Technical Report

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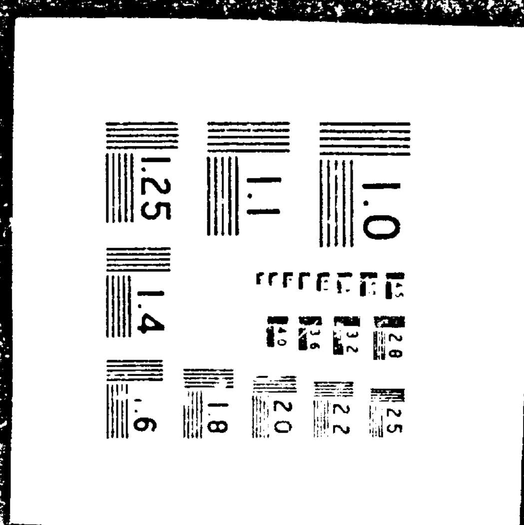

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WT-915

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No. 30 of 240 copies, Series A

OPERATION CASTLE

Project 2.5a

DISTRIBUTION AND INTENSITY OF FALLOUT

REPORT TO THE SCIENTIFIC DIRECTOR

by

R. L. Steton
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T. H. Shirasawa
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January 1956

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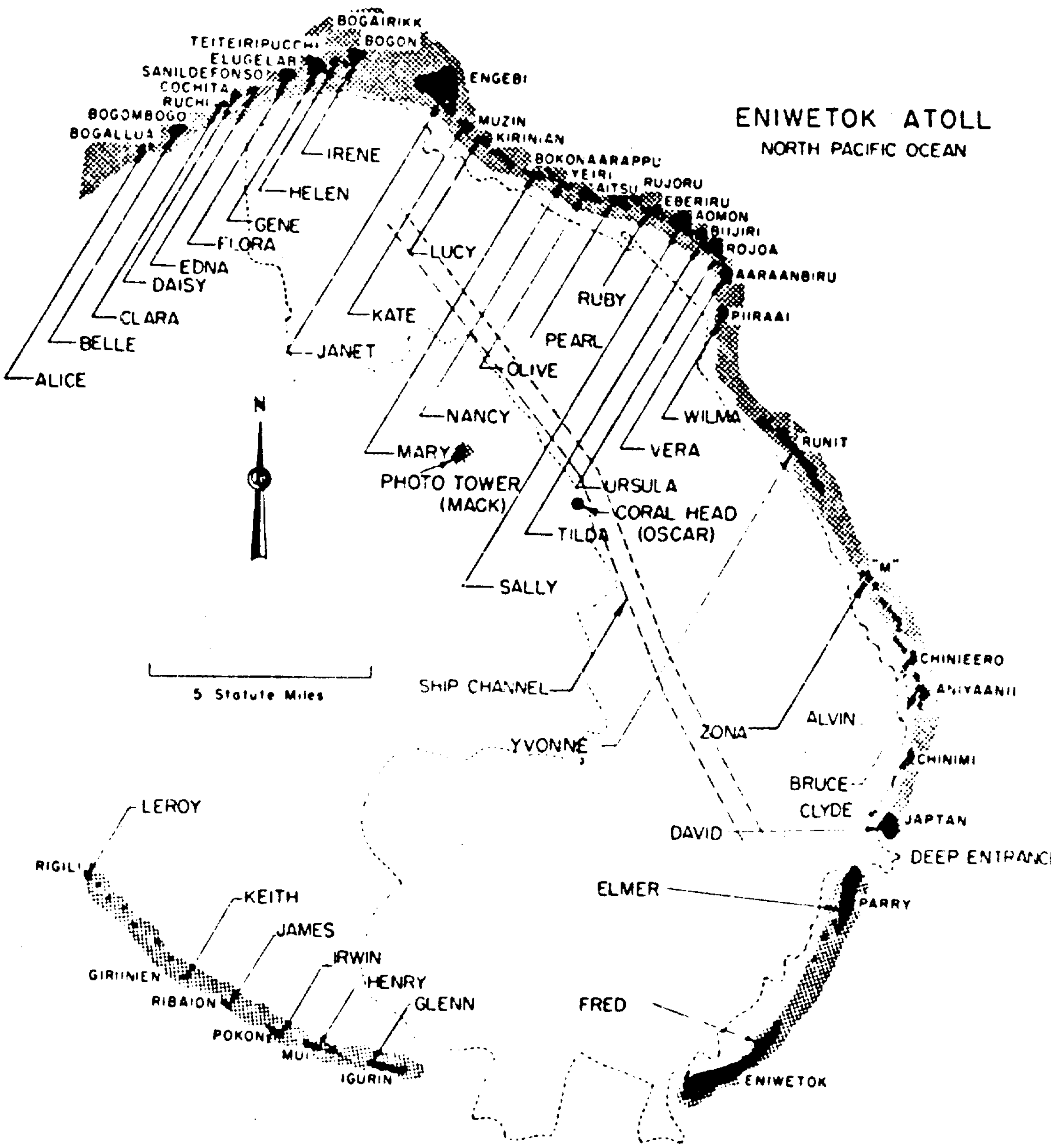
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RIGILI
IRENE
HELEN
GENE
FLORA
EDNA
DAISY
CLARA
BELLE
ALICE
JANET
KATE
LUCY
RUBY
PEARL
OLIVE
NANCY
MARY
PHOTO TOWER
(MACK)
WILMA
VERA
URSULA
CORAL HEAD
(OSCAR)
TILDA
SALLY
N
5 Statute Miles
SHIP CHANNEL
YVONNE
ZONA
ALVIN
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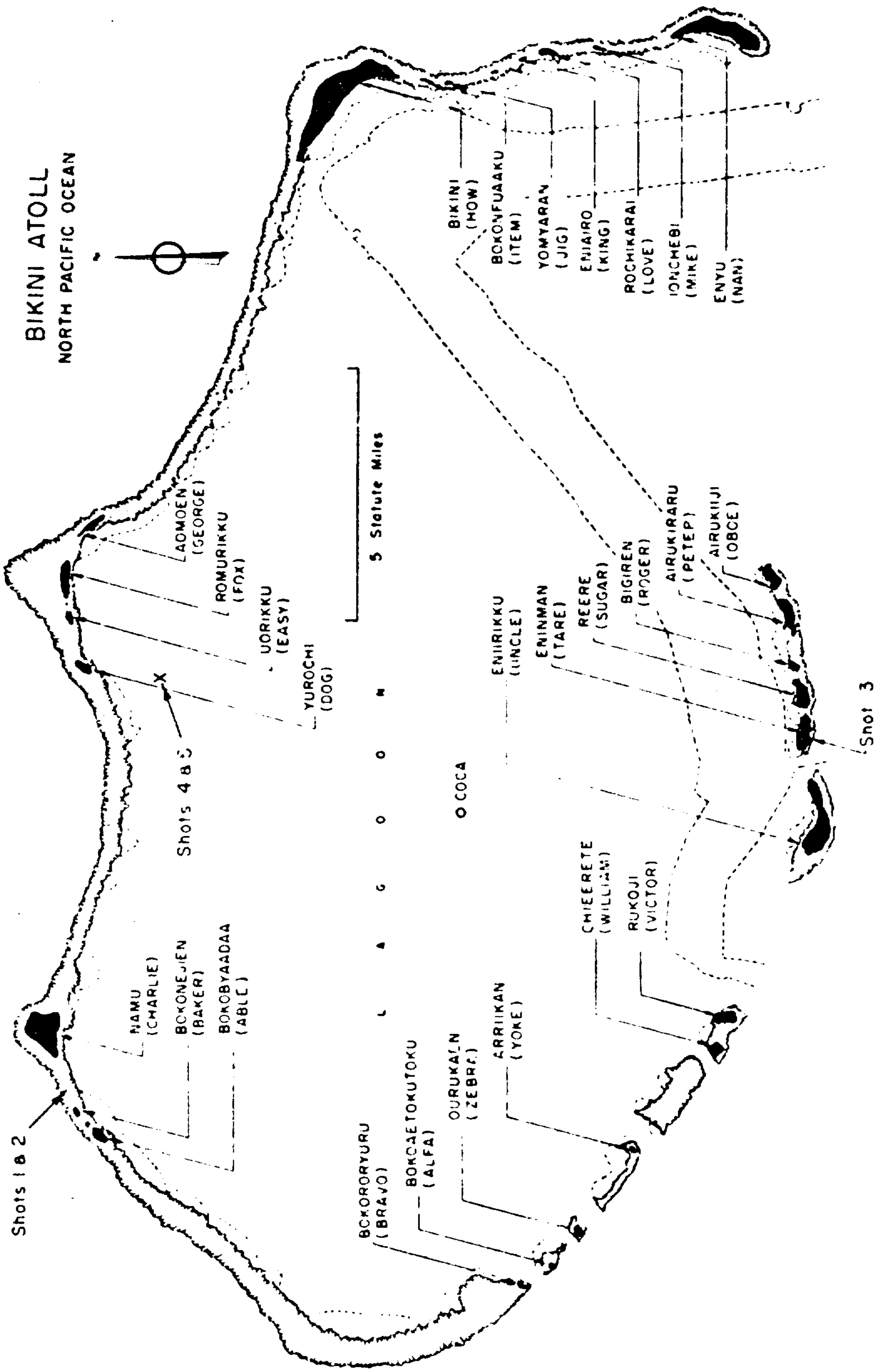

BIKINI ATOLL
NORTH PACIFIC OCEAN
5 Statute Miles
L A G O O N
O COCA
Shots 1 & 2
Shots 4 & 5
Shot 3
NAMU (CHARLIE)
BOKONEJIEN (BAKER)
BOKOBYAADAA (ABLE)
BOKORORYURU (BRAVO)
BOKOAETOKUTOKU (ALFA)
OURUKAEN (ZEBRA)
ARRIIKAN (YOKE)
CHIEERETE (WILLIAM)
RUKOJI (VICTOR)
AOMOEN (GEORGE)
ROMURIKKU (FOX)
UORIKKU (EASY)
YUROCHI (DOG)
ENIIRIKKU (UNCLE)
ENINMAN (TARE)
REERE (SUGAR)
BIGIREN (ROGER)
AIRUKIRARU (PETER)
AIRUKIIJI (OBOE)
BIKINI (HOW)
BOKONFUAAKU (ITEM)
YOMYARAN (JIG)
ENIAIRO (KING)
ROCHIKARAI (LOVE)
IONCHEBI (MIKE)
ENYU (NAN)

[redacted]

GENERAL SHOT INFORMATION

	Shot 1	Shot 2	Shot 3	Shot 4	Shot 5	Shot 6
DATE	1 March	27 March	7 April	26 April	5 May	14 May
CODE NAME (Unclassified)	Bravo	Romeo	Koon	Union	Yankee	Nectar
TIME*	06:40	06:25	06:15	06:05	06:05	06:15
LOCATION	Bikini, West of Charlie (Namu) on Reef	Bikini, Shot 1 Crater	Bikini, Tare (Eninman)	Bikini, on Barge at Intersection of Arcs with Radii of 6900' from Dog (Yurochi) and 3 Statute Miles from Fox (Aomoen)		Eniwetok, IVY Mike Crater, Flora (Elugelab)
TYPE	Land	Barge	Land	Barge	Barge	Barge
HOLMES & NARVER COORDINATES	N 170,617.17 E 76,163.98	N 170,635.05 E 75,950.46	N 100,154.50 E 109,799.00	N 161,698.83 E 116,800.27	N 161,424.43 E 116,688.15	N 147,750.00 E 67,790.00

* APPROXIMATE

S[redacted]

ABSTRACT

The objective of this project was to document the distribution and intensity of fallout from all shots at Operation CASTLE.

Data were obtained for Shots 1, 2, 3, 4, and 6 by use of land stations, anchored lagoon stations, and free-floating sea stations. A complete analysis of the Shot 1 fallout to 300 nautical miles downwind including the development of an experimental model based on fallout particle trajectories is presented as well as data on Shot 2 fallout to 50 nautical miles downwind and the close-in fallout from Shots 3, 4, and 6.

Gamma fields from fallout decayed at rates differing from the $t^{-1.2}$ approximation commonly applied to fission weapons.

Fallout from the surface land detonations was in the form of irregular solid particulates. The geometric mean particle diameter decreased with the distance from the shot points; for Shot 1 the geometric mean varied from 112 μ at Bikini Atoll to 45 μ at Utirik Atoll. The average density of the solid particles from Shot 1 was 2.36 g/cu cm. Little data were obtained on the nature of the fallout from over-water detonations. There was some indirect evidence that the fallout 50 nautical miles downwind from Shot 2 arrived as a fine mist or aerosol. The rate of arrival of fallout at distances close to surface zero was characterized by a rapid rise to a peak; the maximum level of radiation occurred within the first half of the period of fallout.

A continuous 100 hr unshielded exposure after the detonation of a 15-MT device on land, will result in a minimum free field total dose of 100 r over an area as large as 25,000 sq mi.

There is developed an experimental model that provides a means of reconstructing fallout patterns from limited gamma field data and particle trajectories as determined by comprehensive analyses of the meteorological situation.

[redacted]

ACKNOWLEDGEMENTS

The magnitude of this project required the support and cooperation of many groups and individuals. The authors wish to thank the Project Officer, E. R. Tompkins, for his sincere interest and help during the entire course of the work. They are also indebted to the following for their effective contributions to the project.

From U. S. Naval Radiological Defense Laboratory (USNRDL)

1. Fourteen additional investigators from the Chemical Technology Division participated in the field phases of the project. R. R. Soule, P. E. Zigman, W. B. Lane, and E. C. Evans III assumed responsibilities as team leaders.

2. The Engineering Division supplied craftsmen and technicians for field work in addition to services in the development and procurement of instruments. P.A. Covey, D.F. Covell, LTJG R.F. Johnson, USNR, and W. L. Snapp made significant contributions in the field.

3. The Instruments Branch of the Nucleonics Division assisted extensively in the pre-operation testing of buoy identifiers and produced, installed, and serviced the transmitter system used. Two engineers, H. L. Gottfried and F. A. Rhoads, made significant contributions in the laboratory and in the field.

4. The Analytical and Standards Branch of the Chemical Technology Division provided much help in the treatment and analysis of samples. W. H. Shipman and J. R. Lai made significant contributions.

5. The following Project 2.6a personnel gave valuable assistance in the field: W. J. Heiman, R. Cole, J. F. Pestaner, B. Singer, and M. J. Nuckolls.

6. In addition to an effective contribution in the field, J. M. McCampbell of Military Evaluations Group assisted in particle size analyses.

7. C. A. Adams of Chemical Physics Branch, Chemical Technology Division assisted in evaluation of particle size data.

8. D. D. Cole of Procurement Liaison and Materials Control Division assumed responsibility for material control in the field and made a significant contribution in handling return shipments of samples and equipment.

9. CDR H. L. Leichter, USN, LCDR F. J. Sisk, USN, and LCDR J. Cady, USN, projects officers at USNRDL, contributed extensively to investigating

[redacted]

and testing buoy identification systems.

Other

1. The Naval Task Group under the Command of RADM H. C. Bruton, USN, provided extensive support in conducting the sea phase of the project. The following Naval units participated:

USS SIOUX, ATF-75
USS APACHE, ATF-67
USS TAWAKONI, ATF-114
USS EPPERSON, DDE-719
USS RENSHAW, DDE-499

2. Search aircraft support was provided by Commanding Officer, VP-29, under CTG 7.3. LCDR R. J. Wooten, USN, and his air crew contributed significantly to the project, both in evaluating and testing buoy identification systems and in conducting the sea phase at the operation.

3. CDR W. A. Clark, USN, Staff Air Officer, and CDR M. M. Schmidling, USN, Staff Operations Officer, CTG 7.3, provided specific assistance to the project.

4. CAPT J. E. Smith, USN, Commander, Escort Destroyer Division 12, directed sea phase operations during a portion of the operation.

5. Commander, Air Forces Pacific Fleet, arranged for, conducted, and evaluated tests of buoys and identification systems proposed by the laboratory. LCDR R. C. Barton, USNR Staff, COMAIRPAC, conducted the tests.

6. Chief, Bureau of Ships, provided for installation of special radio direction finding equipment on Task Force ships. All arrangements were handled through Code 348 by LCDR J. C. Coates, USN.

7. Project 6.4, TU-13, provided information on the location of fallout areas. W. J. Armstrong made significant contributions in this regard.

8. Lt Col E. A. Martell, USA, Program Director of Program 2, contributed extensively to the planning and direction of project operations at the site, and to the review of this report.

9. The following Naval enlisted personnel were assigned to the project during the operation:

WENZELL, F. J., BM 1/c
RAYMOND, D. G., BM 2/c
MILLER, N. S., BM 3/c

[redacted]

FOREWORD

This report is one of the reports presenting the results of the 34 projects participating in the Military Effects Tests Program of Operation CASTLE, which included six test detonations. For readers interested in other pertinent test information, reference is made to WT-934, Summary Report of the Commander, Task Unit 13, Programs 1-9, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the six shots.
b. Discussion of all project results.
c. A summary of each project, including objectives and results.
d. A complete listing of all reports covering the Military Effects Tests Program.

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ILLUSTRATIONS

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CHAPTER 1

INTRODUCTION

Surface and sub-surface detonations of nuclear weapons on land produce hazardous gamma-radiation fields over areas far beyond the range of physical damage. Fallout which is responsible for the gamma-radiation fields is inherently the least predictable of all weapons effects. Variations in the dispersal and deposition of radioactive debris are affected by meteorological conditions during and subsequent to detonation as well as by the device yield, the charge depth, and the explosion media. Yet, the exploitation of this anti-personnel capability, and the capacity to defend against it, are directly dependent upon the ability to predict those target areas which will be involved. The investigation of fallout, and of the factors which influence it, are therefore important to the development of nuclear weapons and to both military and civil defense planning.

1.1 PREVIOUS FALLOUT STUDIES

Fallout has been observed and documented in some degree at all previous nuclear test programs. In addition, surface and sub-surface high explosive detonations on land and underwater are being studied for their usefulness as models for fallout distribution from nuclear detonations.

1.1.1 Nuclear Tests

Out of a total of 43 nuclear test explosions carried out by the United States, four have produced significant residual radiation fields, the Baker shot, Operation CROSSROADS, surface and underground shots, Operation JANGLE, and Mike shot, Operation IVY. Of these four, only the JANGLE series adequately had documented fallout.

At JANGLE, the residual gamma fields were recorded in detail; in addition, extensive sampling of the fallout events was carried out.[14] Results of the JANGLE surface test were used to predict fallout from Mike shot, IVY. They also formed a basis for fallout predictions for the CASTLE series reported here.

At IVY, although only partial documentation was accomplished,

the operational success of the free-floating buoy station phase was sufficient to encourage the employment of this fallout sampling technique at CASTLE.[7] IVY provided valuable data on the extent of the crosswind and upwind fallout and on the nature of the contaminant to be expected from the land surface detonations at CASTLE.

1.1.2 High Explosive Tests

Six high explosive field tests have been conducted to study fallout. Charges varying from 250 to 50,000 lb of TNT were fired. Emphasis has been placed on shallow underwater explosions.[16] Of a total of 38 shots, 26 were fired in shallow water; 5 in deep water; and 7 on land, both surface and underground. Non-radioactive cobalt and lithium were incorporated in the charges to trace the explosion products. Variables under study include energy yield, charge depth, explosion media, and wind.

1.2 OBJECTIVES

The surface detonations of thermonuclear devices at Operation CASTLE were expected to produce significant fallout over considerable portions of the ocean at the Pacific Proving Ground. The primary purpose of Project 2.5a was to document these fallout areas and determine the militarily important radiation fields which would have resulted had all of the material been deposited on land. Specifically, Project 2.5a was designed to determine the following information for selected shots:

a. Time and rate of fallout and final distribution patterns.
b. Particle size ranges of fallout with respect to time and distance.
c. Amount and distribution of radioactive materials in fallout.
d. Gross gamma decay rates.

The gathering of fallout data at CASTLE was a logical extension of previous fallout documentation. Variation in proposed yields as well as the opportunity to document surface water detonations for the first time made the study of fallout in this operation extremely important.

[redacted]

CHAPTER 2

OPERATIONS

Fallout of military significance generally is characterized in this report as that material which arrives at relatively early times and forms a well-delineated pattern in which the radiation intensity is high enough to affect the conduct of a military mission.* This has been designated "primary" fallout to distinguish it from continent- and world-wide ("secondary") fallout. From IVY it was concluded that "the areas of primary fallout particularly from super-weapons, are quite extensive, and many hours can elapse before the fallout gamma field is completely defined."[7]

The present operations were directed toward documentation of the primary fallout, with investigations of secondary fallout included only where they contribute to the former. Operation plans were made on the following assumptions:

(a) adherence to a reasonably firm shot schedule

(b) availability of adequate logistic support to make necessary collections

(c) scaling of the fallout pattern by the cube root law.

Unavoidable circumstances, the most significant of which prevented the firm shot schedule required by these plans, caused much of the work to be done under less favorable programming devised in the field.

2.1 EXPERIMENT DESIGN

Since the fallout from the CASTLE series was deposited largely over ocean areas, the experiment design required methods of documentation that permitted estimation of what the radiation field would have been had it fallen on land. The estimation was accomplished by: (1) establishing a ratio between the fallout collected per unit area over land,

* A quantitative definition of the term "military significance" or "military importance" depends entirely on the situation existing when the term is applied. Such factors as the target affected, the distance from ground zero, and the arrival time of the debris as well as the extent of its fallout pattern must all be considered. The lower limit below which no combination of circumstances will create a level of military significance may be taken as 5 r/hr at 1 hr.

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(FO_L) and the corresponding field radiation intensity, (R_L); (2) determining the fallout per unit area over water, (FO_W) and; (3) calculating the radiation field, (R_W) which would have occurred had the water areas been land, from the assumed relationship,

$$R_W = R_L \frac{FO_W}{FO_L} \qquad (2.1)$$

This method of approach required the following measurements:

(a) Fallout per unit area on available islands of the test atolls in terms of quantity of radioactivity.

(b) Gamma fields produced at sampling locations.

(c) Fallout per unit area in the lagoon and over the surrounding ocean. It was also important to obtain information concerning particle size and note times of arrival and cessation of the fallout as well as the variations in the radiation field with time.

2.1.1 Predicted Gamma Fields

Estimates of the extent and level of gamma fields expected from the fallout were made for each of the originally planned shots. These predictions were based on scaled surface JANGLE data using the cube root relationship with modifications in the crosswind and upwind patterns indicated by IVY data.7/ It was estimated that the fallout would carry downwind at the rate of 15 miles per hour and that the duration of fallout at any one point would be 2 hr for megaton yields. Values calculated for 2 and 3 hr after detonation represent the levels that would exist had the fallout deposited over extended land areas. Table 2.1 summarizes the predictions for three of the detonations; the effect of decay and the delay in arrival of fallout on the gamma fields can be noted. A discussion of this scaling is presented in Section 6.2.8.

2.1.2 Sampling Stations

On the basis of the predictions given in the preceding section, it appeared that the minimum area of military interest would extend to a distance of 50 miles from the shot point and would have a maximum width of 20 miles. Since it was not possible to predict the sector in which the primary fallout would arrive sufficiently in advance of shot time to permit proper placement and activation of sampling stations, an array completely surrounding the shot point was needed. Experience at IVY showed that, it would not be feasible to document the fallout more than 50 miles from ground zero with available logistic support. The radial array of sampling stations shown in Fig. 2.1 was evolved from these criteria. This plan was modified within the atolls to take advantage of available islands and to permit the placement of simple rectangular grid arrays in the lagoons. In addition, limited sampling stations were arranged at a number of outlying islands.

Operationally, Project 2.5a was divided into two phases - one requiring the collection of data from land and lagoon stations, and the other from sea stations. Logistic support for the land and lagoon phase involved the use of small boats and helicopters while mounting of the

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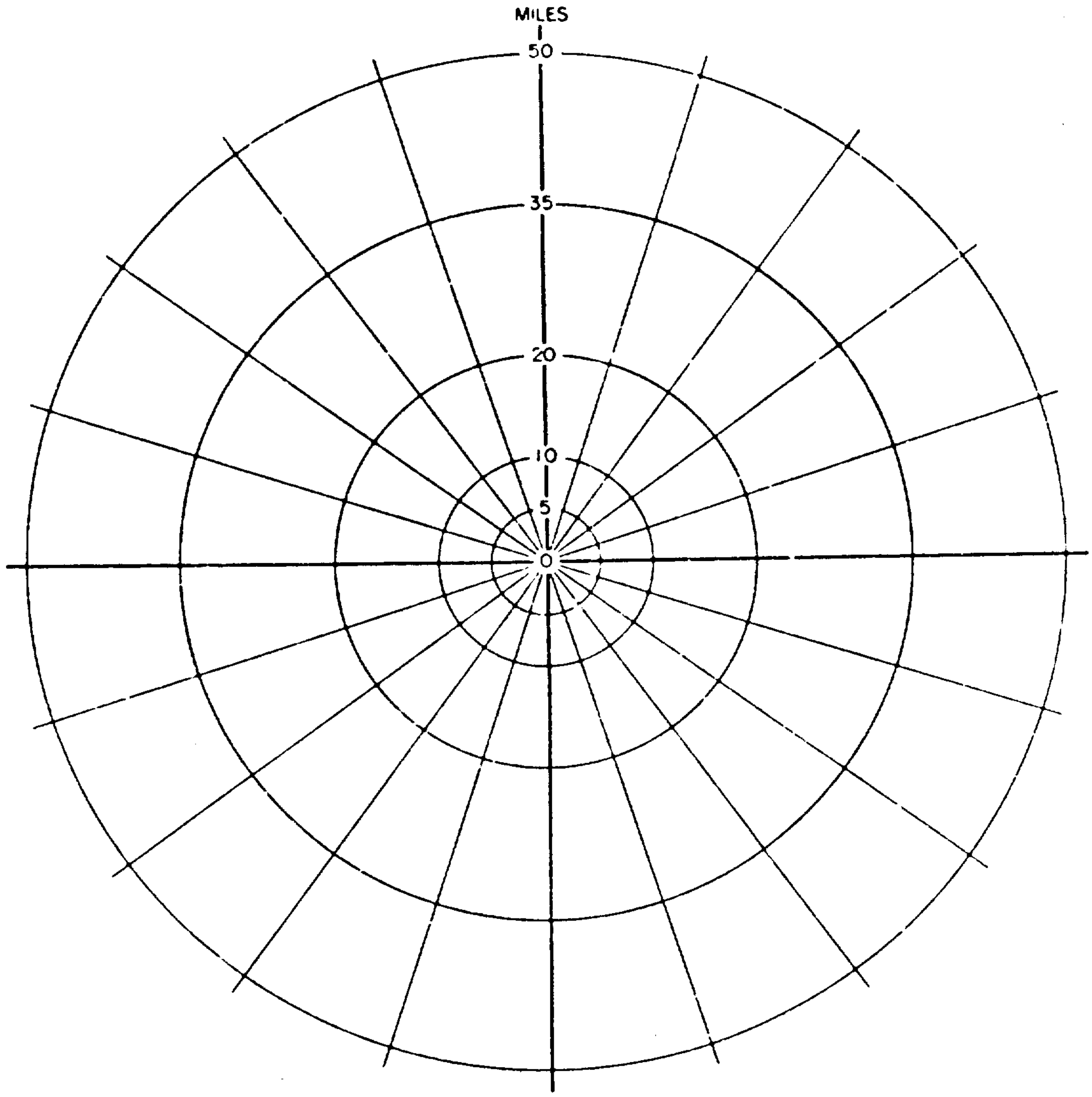

Fig. 2.1 Basic Sampling Array Proposed for all Shots Except Echo Where a Smaller Array was Planned for the Lower Yield Test

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TABLE 2.1 - Predicted Downwind Contamination Levels for Shots 1,2, and 5 after Detonation
(r/hr at times indicated)

Shot	5 n mi		10 n mi		15 n mi		20 n mi		25 n mi		30 n mi	
	2 hr	3 hr	2 hr	3 hr	2 hr	3 hr	2 hr	3 hr	2 hr	3 hr	2 hr	3 hr
1 (based on 6 MT yield)	10,000	5000	5000	4000	3000	3000	1200	2000	800	1500	0	800
2 (based on 3 MT yield)	7,000	4000	3000	2500	1300	1500	700	1100	200	400	0	200
5 (based on 8.5 MT yield)	12,000	7000	6000	5000	4000	4000	2000	2000	1000	2000	0	1000

sea phase required employment of sea-going vessels under the Naval Task Group Command.

2.1.2.1 Land Stations

At Bikini, the islands of Able, Fox, How, Love, Nan, Oboe, Uncle, William, Yoke, and Zebra, were used for sampling and obtaining gamma field measurements. Stations consisted of concrete emplacements with instruments installed in and about them.

At Eniwetok, the islands of Irene, Bruce, Yvonne, Wilma, Leroy, Alice, Janet, and Nancy were used for sampling and for obtaining gamma field measurements. Where possible, station emplacements remaining from IVY fallout sampling were utilized; otherwise instruments were placed in the open and suitable tie-down arrangements improvised.

Stations were established on the following outlying islands: Rongerik, Kusaie, Majuro, Ponape, Wake, Guam, Kwajalein, and Johnson.

2.1.2.2 Lagoon Stations

Rectangular-grid arrays of stations were established for lagoons of both test atolls, as shown in Figs. 2.2 and 2.3. These consisted of anchored buoys to which rafts were attached (see Fig. 2.4).

2.1.2.3 Sea Stations

Sampling in the open ocean was accomplished by means of free-floating buoys to which, in some cases, rafts were attached. Plans were made to provide the complete coverage indicated by Fig. 2.1 for one land

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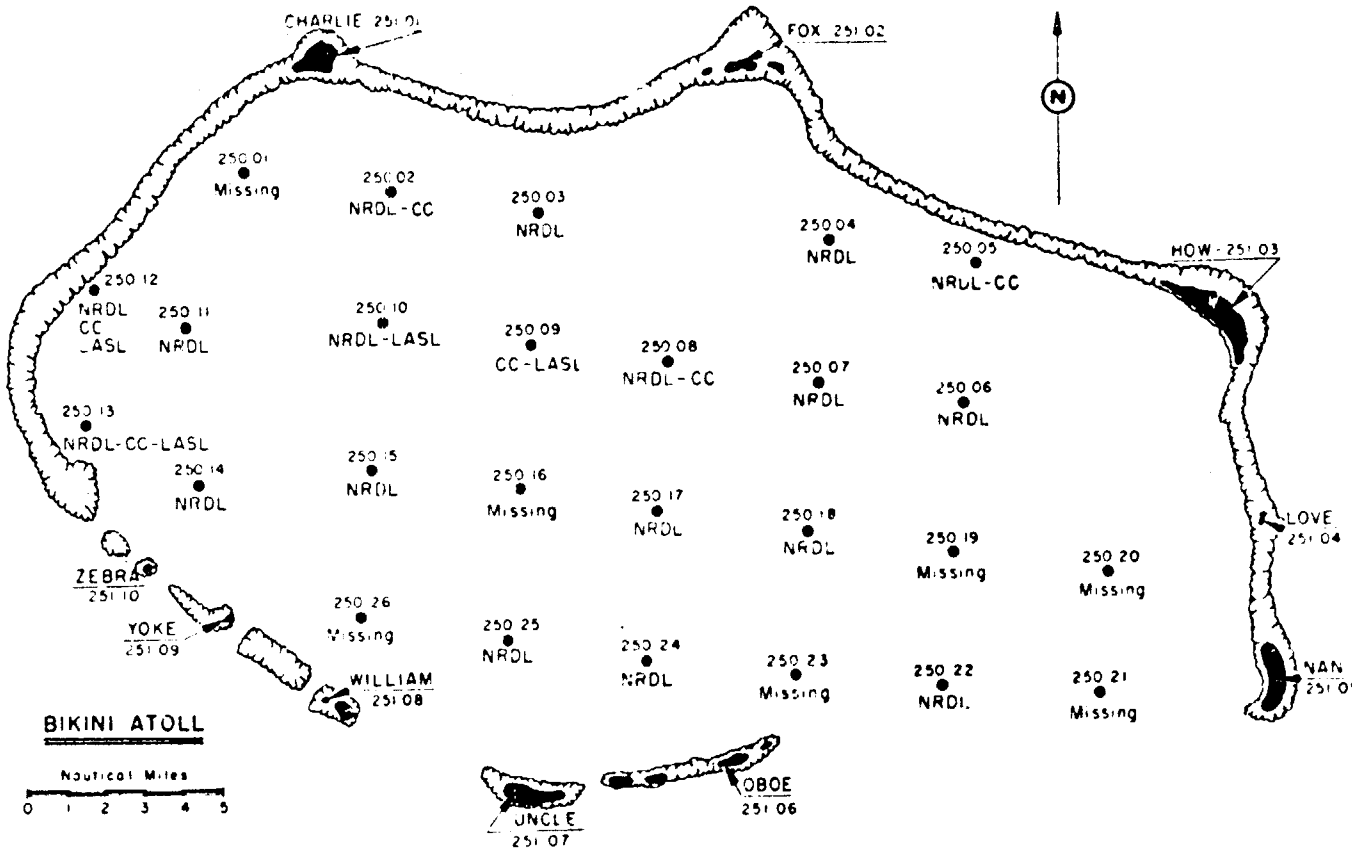

Fig. 2.2 Lagoon and Island Station Array for Bikini Atoll

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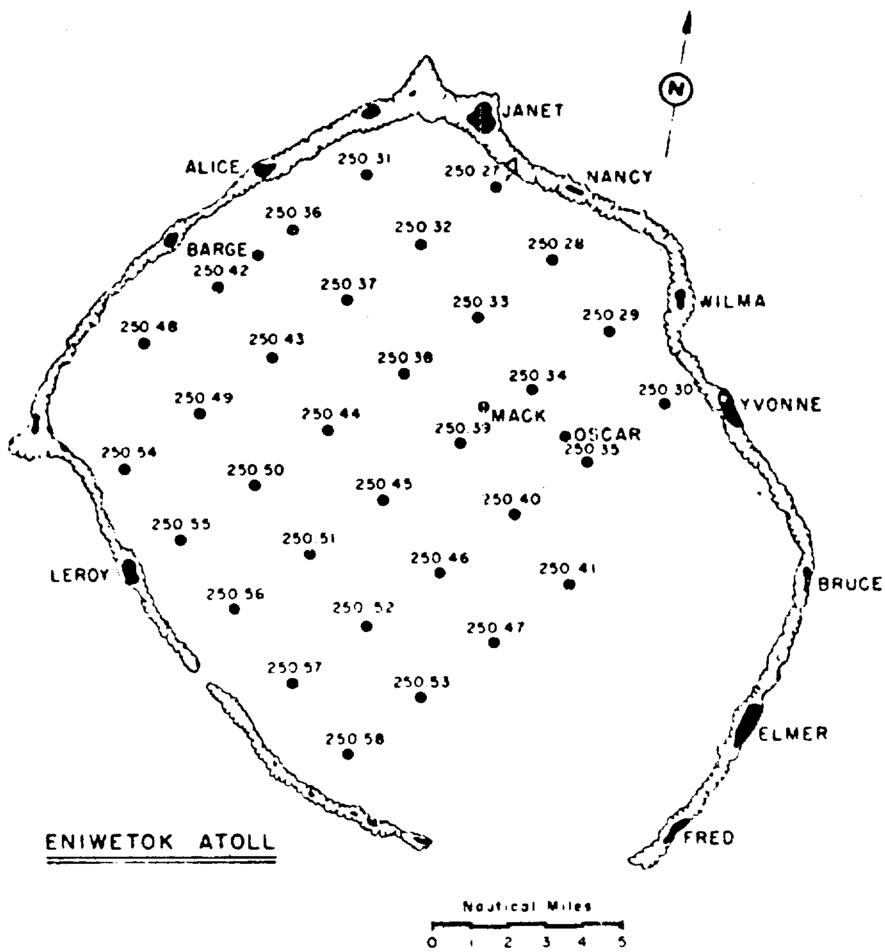

Fig. 2.3 Lagoon Array for Eniwetok Atoll

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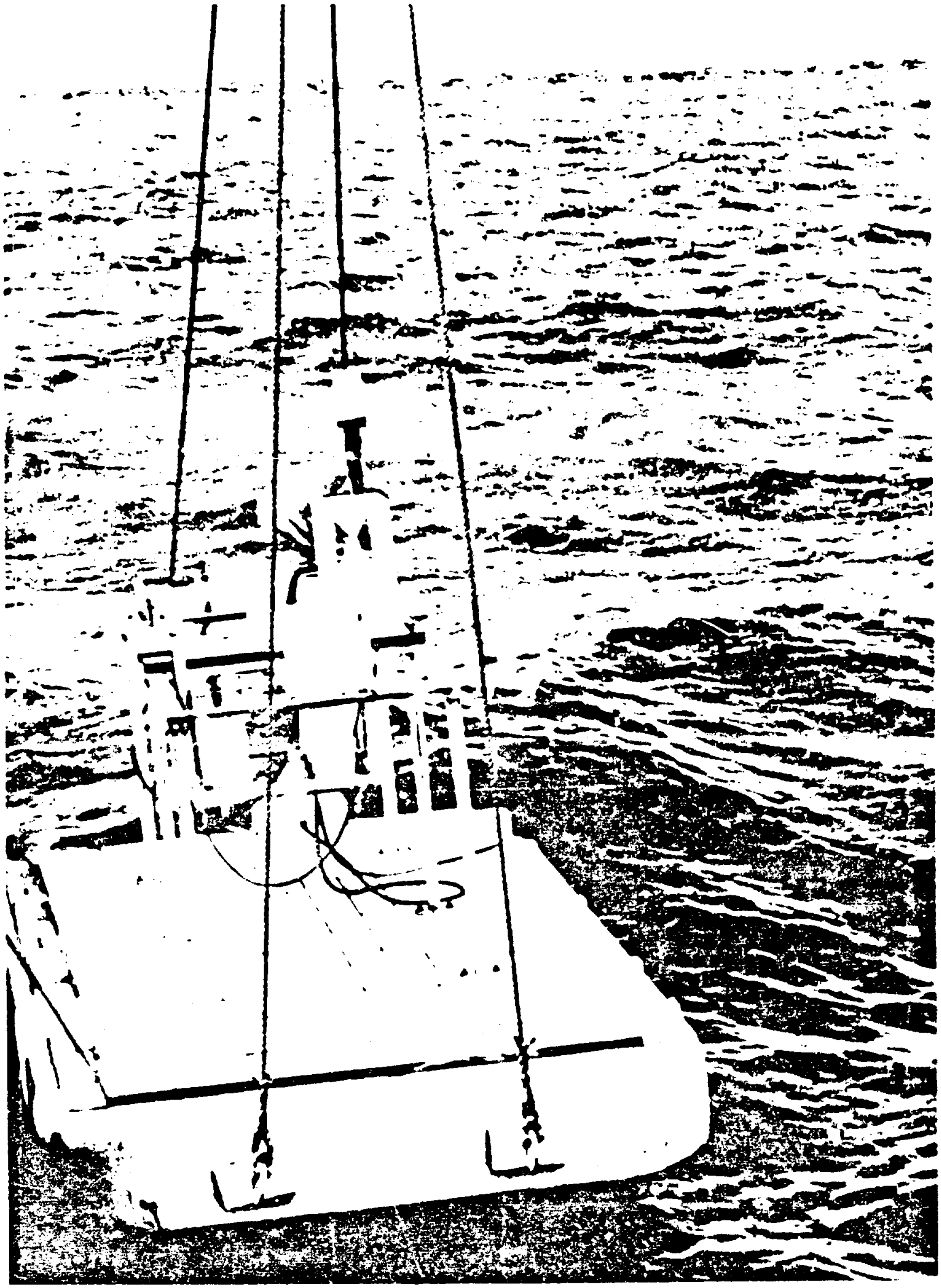

Fig. 2.4 Lagoon Station Being Placed

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and two water shots in the megaton yield range. A smaller array extending to 15 miles was planned for the lower yield Echo shot.*

2.2 LAND AND LAGOON PHASE

The land and lagoon phase of operations took place at Bikini Atoll for Shots 1, 2, 3, and 4 and at Eniwetok for Shot 6. In addition extensive preparations for Echo were made at Eniwetok. The instrumentation of the island and the lagoon raft stations is discussed in Chapter 3.

The preshot preparations at Bikini involved readying the equipment, calibrating the instruments, and emplacing them at the island and lagoon raft stations. This was completed a week prior to Shot 1. Final checks were made on the equipment at all the existing stations 1 to 2 days before shot time to assure complete readiness and operational efficiency. Preparations were also made for the recovery operations and for the re-instrumentation of the stations.

Participation in all detonations except Shot 5 was achieved although not to the extent originally planned. The lesser participation was due to the destruction of equipment by the fire in the compound at Tare following Shot 1. Tables G.1 through G.20, Appendix G, show the degree of instrumentation and recovery for each shot.

2.3 SEA PHASE

Free-floating buoys were selected for sampling fallout in the open ocean on the basis of their evaluation at IVY.[7] Each buoy station was so located that it was expected to drift to the desired position by shot time. Records were kept of the locations and times of placement and recovery of each buoy. From these data, positions at shot time were estimated by assuming that each buoy drifted in a straight line at a constant speed. It was essential that the time the buoys were at sea be held to a minimum so that their location at shot time could be estimated as accurately as possible. For this reason the array for each test was laid out within 36 hr of the proposed shot time and recovered as soon as possible afterwards.

Sea phase operations were mounted from Eniwetok Atoll for all shots. Detailed direction, once Naval units were committed, was accomplished from ships based at Bikini Atoll or from vessels actively participating in Project 2.5a operations.

2.3.1 Pretest Preparations

The buoys and associated equipment were assembled and tested at Parry Island. Liaison was established with the Naval Task Group and plans for conducting the sea phase were made. These plans consisted of loading two sea-going tugs with equipment at Eniwetok Atoll, after which the vessels proceeded to sea to lay the buoys. After completion of the buoy laying operations, the tugs retired to a safe area to await the shot. Upon receipt of clearance from the Naval Task Group Commander following the shot, the tugs proceeded to recover buoys after which they returned to Eniwetok to off-load. Detailed plans for laying the buoys,

* Not fired.

taking into account steaming times, time required for laying, and drift and set of the currents, were prepared by the project for each shot in which it participated. They were then forwarded to the Naval Task Group for approval and incorporation into their event plan. Project personnel accompanied the ships on their missions to advise and assist in the handling of samples and employment of project equipment.

2.3.2 Rehearsals

Arrangements were made with the Task Force to schedule ship and aircraft support for pre-operation rehearsals for the following purposes:

(a) To indoctrinate personnel in the process of laying and retrieving buoys and rafts and in the handling and mounting of project equipment at sea.

(b) To test the radio identification and location systems to be used.

(c) To obtain information on current velocities in the ocean about the two test atolls.

(d) To test radio transmission from the buoys for compatability with other transmissions used throughout the Task Force.

In the rehearsals a limited number of buoys were laid around the atoll. Location and recovery operations were started the following day. These rehearsals furnished valuable information regarding various phases of the operation and acquainted the crews of the ships with the problems to be solved. Under normal conditions the radio transmitter operated successfully. It usually could be detected on the ship's direction-finding gear out to 15 or 20 miles and greatly facilitated locating the buoys. The ocean currents were found to vary greatly both as to set and drift. (See Appendix H.) It became apparent that the ability to mount the sea phase would be strongly influenced by the sea state. The handling problem aboard ship, the performance of the buoys and transmitters at sea, and the detection and homing problem all were adversely affected as the sea state increased. It was concluded that a full array could be placed as planned only if the seas were relatively calm, and that the cut-off point at which buoy operations must be discontinued would be a sea state of four. It was further concluded that operations in seas approaching state four would result in damage and loss of equipment in some degree, as well as extending the time required to carry out all phases.

The rehearsals showed that the loss rate of buoys would probably be greater than anticipated. Thus in the planning and conduct of the sea phase for each shot careful consideration had to be given to conservation of equipment for the remaining shots in the series.

2.3.3 Shot Participation

At the start of CASTLE, 124 buoys completely equipped with radiotransmitters and sampling devices were available. Twenty of these units less radiotransmitters were used to augment the sampling program at Bikini following the destruction of Project 2.5a equipment and facilities after Shot 1. The disposition of the buoys during the sea phase

[redacted]

TABLE 2.2 - Summary of Sea Phase Operation

Operation	Buoys Prepared for Test	No. of Buoys Laid 1st Attempt	2nd Attempt	3rd Attempt	Buoys Recovered	Buoys Lost	Cumulative Losses
Rehearsal	12	11	-	-	4	7	7
Shot 1	60	none	15	-	9	6	13
Shot 2	60	6	14	14	11 (all from 3rd laying)	23	36
Additional Eniwetok Drift Test	4	4	-	-	2	2	38
Shot 4	40	26	-	-	7	19	57
Shot 5	20	14	6	-	4	16	73
Shot 6	5	4	-	-	0	4	77

is summarized in Table 2.2. For the sea phase 114 buoys were laid; of these 77 were lost. Of the 37 recovered, 10 were damaged beyond repair and 17 required a major overhaul.

The conditions under which the shot participation in the sea phase were made are best illustrated by Shot 4. Here placement and recovery of the buoys were done under the direction of CTG 7.3 and his staff with the advice and assistance of a project representative. Control was maintained through the Combat Information Center (CIC) aboard the command ship, USS Curtiss. All necessary communication facilities were made available. Information on planting progress was relayed regularly to the CIC where it was immediately plotted. On the advice of the staff aerologist, late changes were effected in the array corresponding to shifts in wind patterns which would affect fallout. The first deferment was a 24-hr delay of the shot after all laying operations had ceased. The ships involved were directed to proceed to favorable positions to commence placement of additional buoys. With the second deferment announced before additional buoys were laid and it being an indefinite delay of the shot, recovery operations were started immediately. Using a standard CIC system of coordinated aircraft and surface search, radar fixes were rapidly obtained on 11 of the 26 buoys and recovery ships were directed to pick up positions. Buoys were located by homing on the radio signal transmitted from each. After recovery of seven buoys, the search was discontinued and the ships were ordered to Eniwetok to prepare for the next test scheduled there 48 hr later.

On the basis of this experience along with recovery from Shots 1 and 2, it was concluded that the buoys and associated equipment performed satisfactorily. Although rough seas interfered to a great extent in the sea phase operations, fallout from most of the shots could have been collected fairly satisfactorily had the shot schedule been firm. The combination of deferments and rough seas resulted in the loss of

[redacted]

considerable equipment. Of the buoys recovered fallout data were obtained from only 20 on Shots 1 and 2.

Data were obtained on the currents in the vicinity of the two atolls. These data along with similar data from IVY are included in Appendix H.

2.3.3.1 Shot 1

The array planned for the first shot is shown in Figs. 2.5 and 2.6. This was considered to be a reasonable effort based upon rehearsal experience. Heavy seas prevented placement of all except the portion shown in Fig. 2.6. This attempt to sample the fallout was unsuccessful because the primary fallout occurred in another sector. This failure indicated the importance of having a 360° array around ground zero.

2.3.3.2 Shot 2

The original plan for Shot 2 called for a complete 360° array similar to that planned for Shot 1. A portion of this plan was executed twice but in each case the shot was deferred for an indefinite period. The buoys placed on these occasions were lost. An alternate plan which required less time to implement was developed for use in case notice of the shot date was given too near shot time to permit laying the original array. This alternate plan was used for Shot 2. See Fig. 2.7.

2.3.3.3 Shot 4

The buoy array and details of the operation plan for Shot 4 are given in Appendix A. This plan was successfully carried out on the basis of a firm schedule for the fourth test. However the effort was nullified by a very late deferment of the shot. Only 7 of the 26 buoys were recovered. When the shot finally did occur no buoys were in the primary fallout zone.

2.3.3.4 Shot 5

Buoys were laid in two separate attempts to document fallout on Shot 5. The first array was similar to that employed for Shot 2 (Fig. 2.7). The second was intended to augment the first following a 24-hr delay of the test. Further deferment nullified this effort, also. Participation by project personnel in the water sampling program was effected for Shots 5 and 6. Results of this field work have been reported elsewhere.4/

2.3.3.5 Shot 6

Four buoys were planted from the ships assigned to Project 6.4, commencing 5-hr prior to the shot. Heavy seas prevented recovery of any units.

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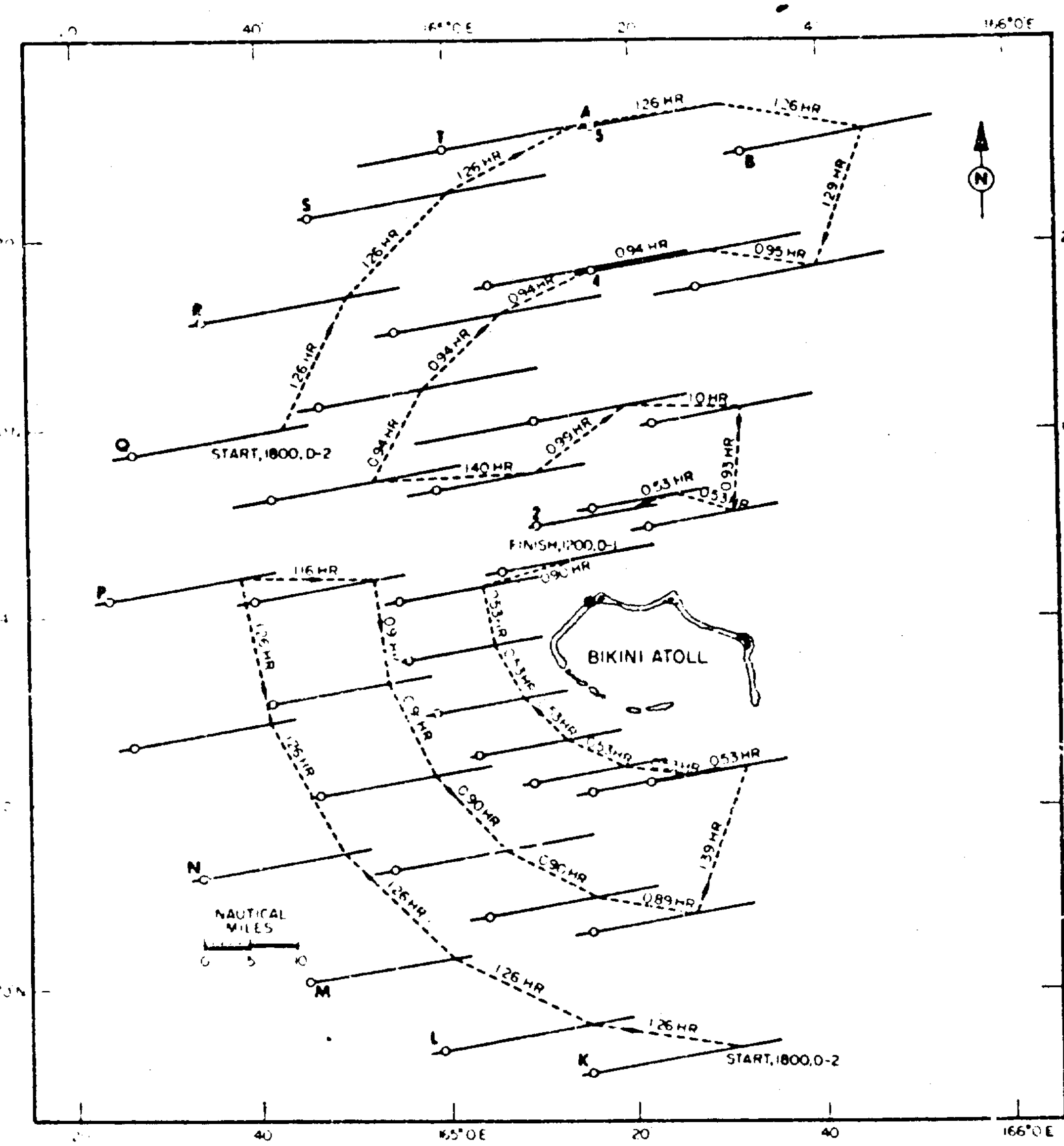

Fig. 2.5 Shot 1, Planned Sea Station Array

[redacted] A

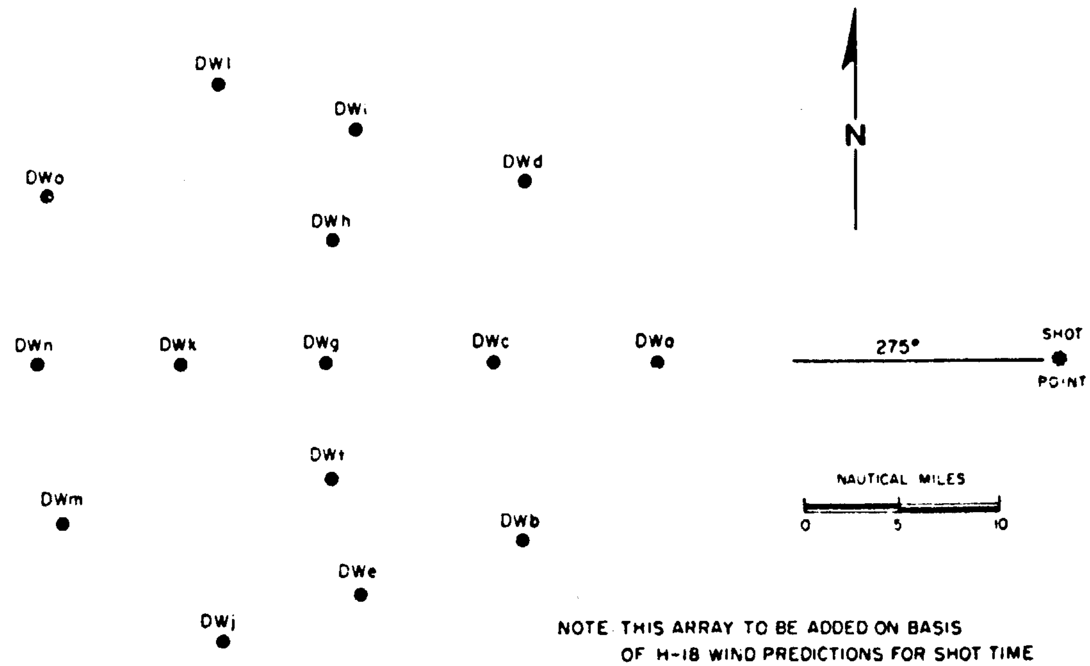

Fig. 2.6 Shot 1, Sea Station Array

[redacted]

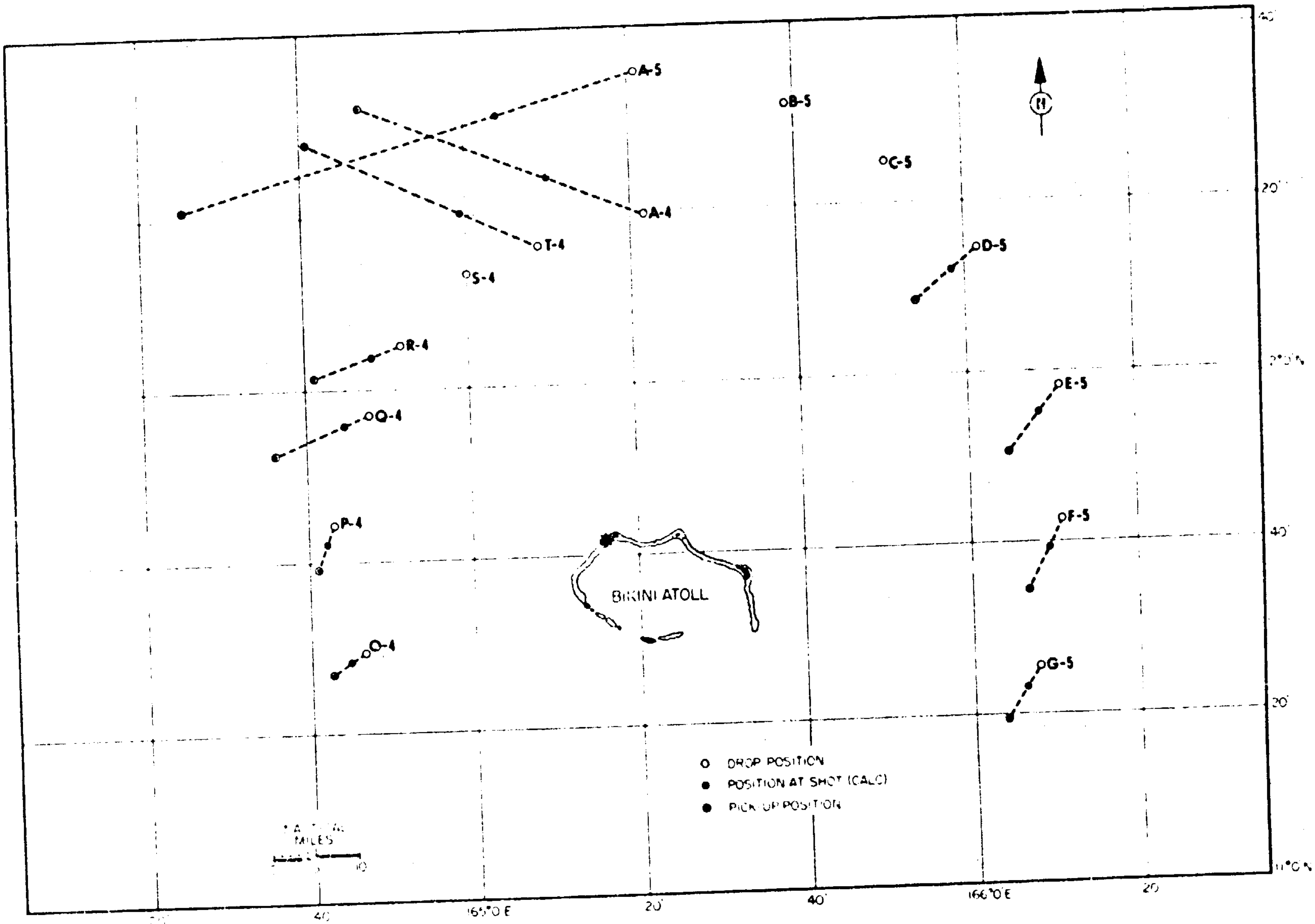

Fig. 2.7 Shot 2, Sea Station Array

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CHAPTER 3

INSTRUMENTATION

The apparatus used in this operation was designed: (1) to collect fallout samples, and (2) to measure the gamma radiation from the fallout. Various collecting devices were used to gather total fallout on a known area and increments of fallout as determined by a time or quantity basis. Also, aerosols from a known volume of air were collected. Many of the devices were similar to those used in Project 5.4 at IVY; 7/ others were prototypes being field tested for the first time. Besides the fallout collectors and the devices for measuring radiation fields, accessory equipment was required to start and stop the apparatus and to furnish power. In some cases the accessory equipment had to meet more stringent requirements than did the primary collecting devices. A prime example was the free-floating buoy which had to be positively identifiable by Task Force security patrols and had to be provided with a means for locating it from a ship many miles distant. A year of intensive investigation and testing was spent in selecting and developing a satisfactory system,* for locating the buoys.

3.1 DESCRIPTION AND OPERATION OF THE EQUIPMENT

Instrument designs were based on specific collecting requirements within the limitations imposed by certain mechanical, electrical and operational restrictions. The following sections give a brief summary of the design and operation of the equipment.

3.1.1 Total Fallout Collectors

Two methods were used to obtain samples of total fallout. A polyethylene funnel-and-bottle arrangement consisting of a 7-in. diameter funnel and 1-gal bottle (Fig. 3.1) was used at all stations to collect and retain deposited material. The other collector, also used at all stations, consisted of a horizontal 1-ft square of transparent

*"Development and Testing of Identification System for Project 2.5a Free-floating Stations at Operation CASTLE." Project Officer, Proj. 2.5a ltr 3-905C-443A of 24 Nov. 1953 to CTU 13. USNRDL Document 009472 Nov. 1953 (SECRET).

[redacted]

Fig. 3.1 Total Collector

[redacted]

gummed paper mounted on water resistant cardboard. In both methods, the collectors were continuously exposed from the time of their placement until recovery. Samples obtained were used primarily in determining the final fallout distribution patterns.

3.1.2 Differential Fallout Collector

The differential fallout collector (Fig. 3.2), employed to collect fallout as a function of time was an improved version of the belt sampler used during IVY. It was employed on most land and many lagoon stations. It was designed to expose 40 jars consecutively at 5 min intervals after being started by a signal from a light-activated trigger. This equipment was powered by a 6-v, 110-amp-hr storage battery.

3.1.3 Film Badge Pack

Use was made of the National Bureau of Standards film badge pack to measure the integrated gamma radiation dose at each station where fallout was collected. These dosimeters were provided and processed by Project 2.1 personnel.

3.1.4 Gamma Time-Intensity Recorder

The gamma time-intensity recorder was used in conjunction with a data reduction system, to provide long-term, continuous information relative to radiation fields. It consisted of a series of ionization chambers, associated electrometer and relay circuitry, and Esterline-Angus pen recorders.[12] The information for each chamber was stored as a simple pulse, each of which corresponded to the basic increment of gamma radiation for the given chamber. The system was essentially of the charge integrating autorecycle type, the chamber being recharged to its original voltage as each basic increment of radiation was received and recorded. The basic chamber increments were 0.1 mr, 10 mr, 1 r, and 100 r covering the range from 0.1 mr/hr to 10,000 r/hr. The instrument was powered by ten 150-amp-hr batteries, eight of which were in series providing 48 v for the relay circuits and power to drive the pens in the Esterline-Angus recorder; the other two were in parallel providing 6 v for the filaments of the amplifier tubes in the detector heads. A spring-driven mechanism moved the paper in the Esterline-Angus recorders.

3.1.5 Prototype Collecting Devices

Several prototype instruments were tested for their possibilities as fallout and base surge samplers. Two such instruments were the electrostatic precipitator and the automatic water drop collector. The samples collected by these instruments were analyzed at the USNRDL. The results are given elsewhere.[18]

The electrostatic precipitator was developed as a fog sampling device to obtain information on size, radioactivity, and ionic content of individual liquid aerosol particles. The sampling was accomplished

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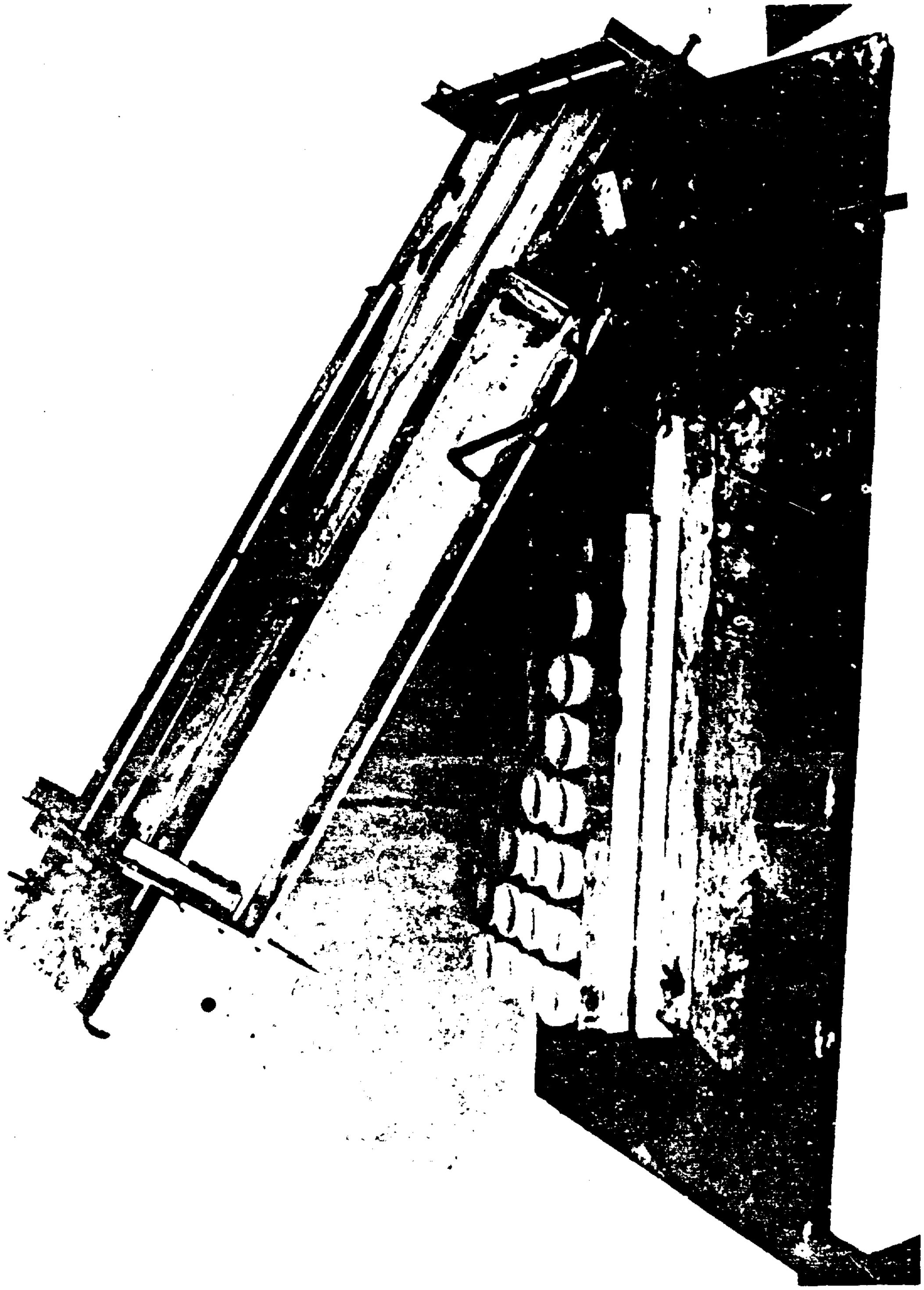

Fig. 3.2 Differential Fallout Collector

[redacted]

by precipitating the fog by means of an electrostatic field onto a continuously moving, specially sensitized film. Film reels were later removed from the device, developed, and analyzed. The electrostatic precipitator was powered by a 1 KVA motor generator and was capable of sampling for a maximum of 6 hr. At island stations it was started by a signal from a light trigger and manually on the YAG's.

The automatic water drop collector was a device for collecting raindrops in flour filled trays when they were retained as pellets of dough. After a pre-determined number of rain drops had been collected, the device automatically changed trays. The collector was started by a signal from a light trigger. The mechanism for changing trays was driven by compressed gas and was triggered by a rain drop contacting a sensitive element. The area of the sensitive element was adjusted so that there was a high probability that a tray would be changed only after a pre-determined number of drops had fallen into it.

3.1.6 Triggers

The principal trigger was a light-activated device consisting of a trigger head, a trigger box, and a battery and power cable assembly (Fig. 3.3).

A prototype radiation trigger was also tested as a back-up trigger. Its sensitivity was so high that it could not be used on the contaminated islands after Shot 1. It may prove to be satisfactory after some modifications.

Simple pressure-actuated triggers were designed and constructed at the site to alleviate the shortage of triggers that occurred when spares were burned after Shot 1.

3.1.7 Free-floating Buoys

Free-floating buoys were used as collection stations in the sea areas around Bikini Atoll. Figure 3.4 shows the following details of construction: Platform to mount the gummed paper collector; antenna whips; antenna coils; identification flag; total collector; buoy float containing the radio transmitter and battery power; and keel mount. Not shown are the weight at the bottom of keel mount and the film badge on the mast 2 ft above deck.

The identifiers on the floats were single-stage crystal-controlled radio transmitters, operating on the following authorized frequencies* 1309.375, 1243.75, 1206.25, 1159.375, 1129.375, 1087.5, 1062.5, 1026.875, 987.5, and 941.875 kc. These units had a useful life of 4 to 6 days before the batteries had to be re-charged. The buoys were identified and located by radio direction-finding gear aboard Naval Task Group ships and aircraft.

3.2 EVALUATION OF STATIONS AND EQUIPMENT

It is difficult to make a fair evaluation of the station and equipment at CASTLE because numerous changes in shot scheduling and the

* Circuit No. J113, assigned by letter from Headquarters, TG 7.1, JTF-7, J-22227, 15 Dec. 1953.

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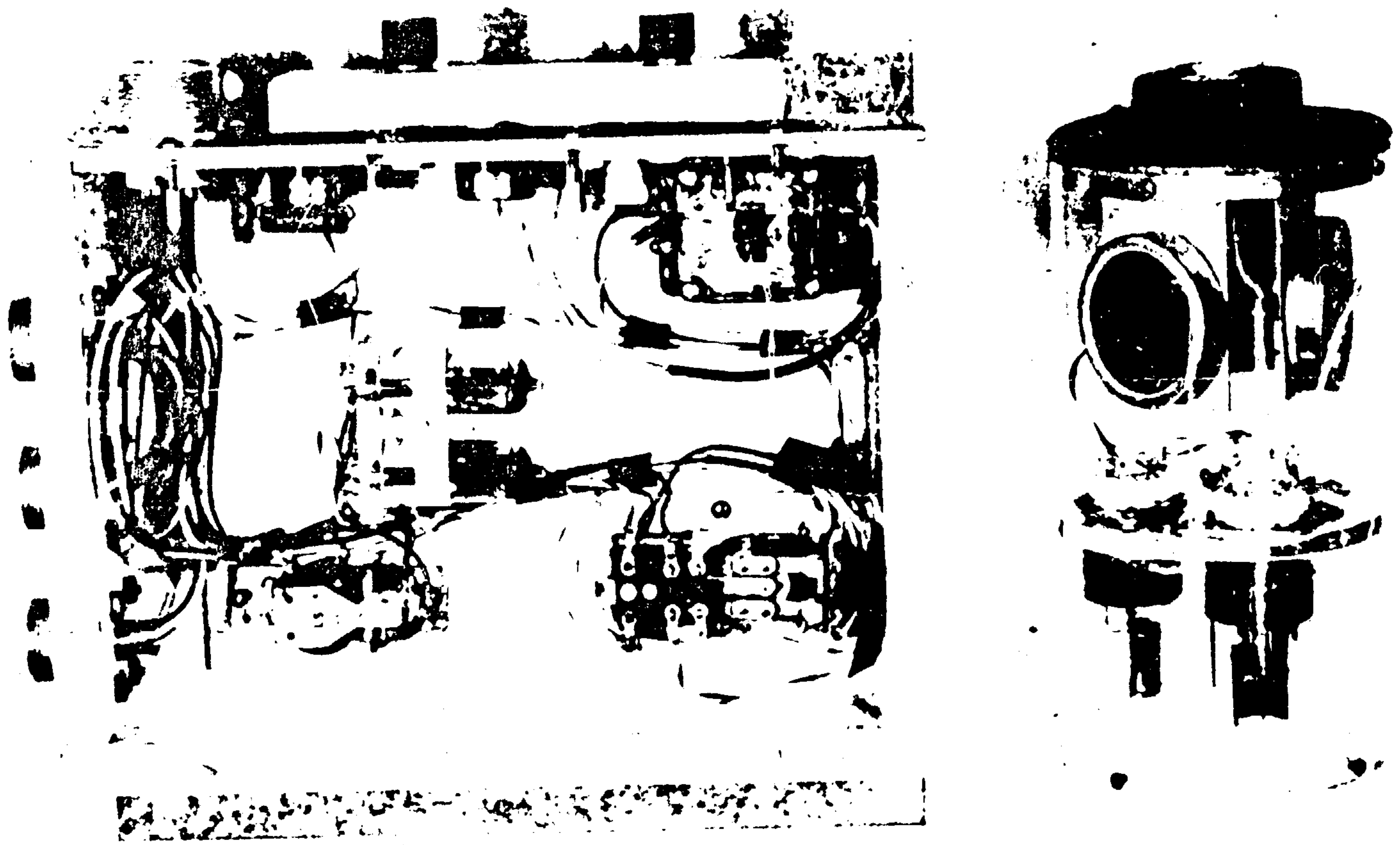

Fig. 3.3 Light-Actuated Trigger Assembly

extended period of the operation required the equipment to function under conditions considerably different than anticipated. Destruction of supplies and spare parts by the fire after Shot 1 severely hampered re-conditioning damaged apparatus and correcting anomalies as they developed. Changes in shot scheduling particularly curtailed the usefulness of the free-floating buoys. Many of the devices which had performed satisfactorily at IVY and at the HEM tests were badly corroded during the long period of CASTLE. In general, experience at CASTLE emphasized the advantages of simple equipment that could be modified readily to meet a variety of conditions. Likewise, it stressed the need for using non-corrosive materials in the construction of all apparatus exposed to the atmosphere. A brief evaluation of the stations and apparatus used at CASTLE is given here as an aid for planning future field programs.

3.2.1 Island Stations

Collecting devices were located in concrete-lined dugouts. The IVY stations[7]/had been constructed on the ground level. In both cases sand tended to drift into collecting devices indicating a larger quantity of solids than actually fell after a shot. It would be preferable for future operations if the collecting equipment could be located above the ground level and still be protected against blast damage.

3.2.2 Lagoon Stations

The raft stations were well designed except for a few details. Greater care should be taken to insure that the battery is protected from sea water. The moorings were not installed as specified originally

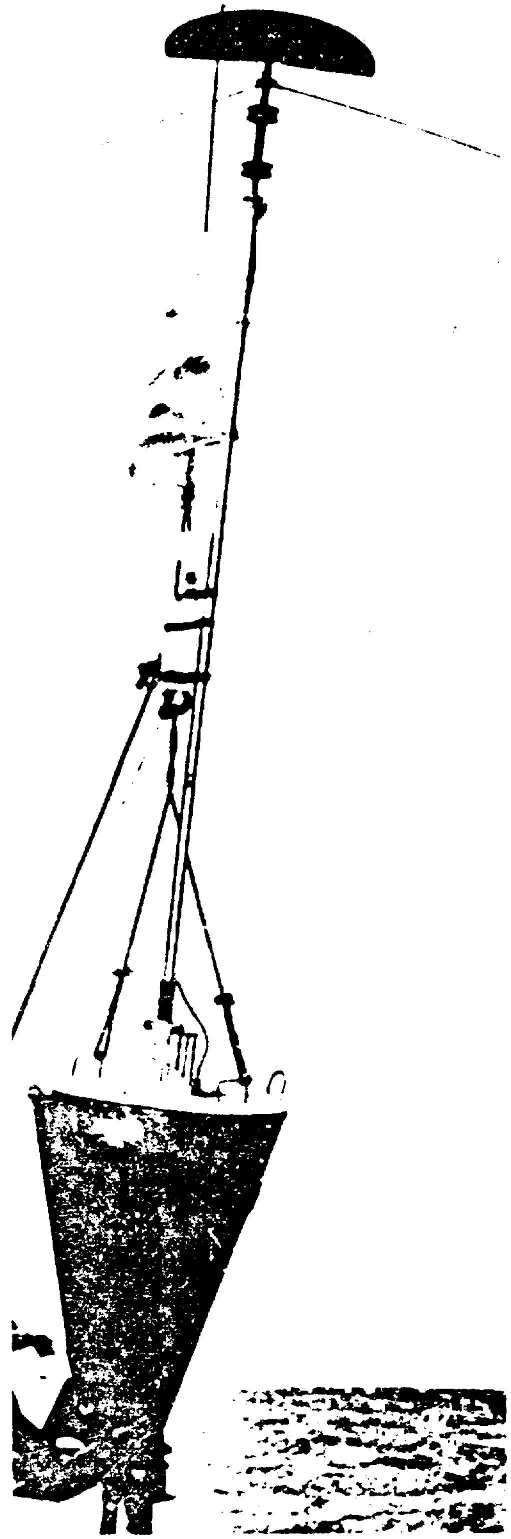

Fig. 3.4 Free-floating Sea Station Being Launched

[redacted]

and many had to be replaced during the operation. After Shot 1, several rafts capsized although they were designed to withstand the effect of a 10-MT weapon, 5 miles distant.

3.2.3 Free-floating Sea Stations

The performance of free-floating buoys as collecting stations was important to the main objectives of the present work. Although little data on fallout were secured from these stations, sufficient information was obtained to determine the performance of the equipment and the suitability of the method. The following observations are pertinent:

(a) Performance of the buoys and associated equipment was satisfactory. The low-frequency transmitters together with the radio direction-finding gear aboard Naval units provided an adequate system for locating and identifying the buoys. The handling problem in placement and recovery raised some difficulties, particularly in increasing seas, but was satisfactorily met.

(b) The free-floating buoy system was unsatisfactory for documenting fallout under the conditions of shot scheduling which prevailed after the first test. This statement would be true of any similar system having the prerequisite that the test take place within a 24-hr period specified 24 to 48 hr in advance.

3.2.4 Total Collectors

From evidence given in Sections 4.2.1 and 5.1.2, modifications in the design of total collectors are indicated. Nevertheless, both devices used made satisfactory collections under some exposure conditions. As expected from other experience, the principle of using simple continuously open (collecting) sampling devices was found satisfactory whenever only total radioactivity deposited per unit area was to be determined. Such devices are not satisfactory where it is desired to preserve the characteristics of the fallout because dilution by extraneous rain and dust occurs.

3.2.5 Belt Sampler

The belt sampler was handicapped by too many moving parts which were exposed to the elements. It was badly corroded by sea spray; sand lodged in the gears or under the belt and caused the sampler to function poorly. The collection from this sampler on Shot 1 was much better than on subsequent shots. Considerable valuable data were obtained as shown in Chapter 4.

3.2.6 Liquid Droplet Sampler

The prototypes tested at CASTLE failed to operate in most instances. This failure was due both to a faulty triggering mechanism for indexing the trays and to the absence of liquid droplets in the fallout from most shots. Nonetheless this differential collector has

several promising features, one of which is its adaptation for collecting dry particles. The mechanical parts are entirely enclosed. It is powered by compressed gas which makes a compact source that is easily recharged and largely unaffected by atmospheric conditions. This device needs further engineering development. It will be field tested again at future operations.

3.2.7 Electrostatic Precipitator

This device for collecting small aerosol droplets was the most complicated sampling apparatus used on Project 2.5a. Its large power requirements were supplied by a motor-generator set. It was almost impossible to keep this equipment in operating condition, particularly after the fire caused by Shot 1 which destroyed all the spare parts for the electrostatic precipitator. Definite evaluation of the usefulness of the electrostatic precipitator ... collecting aerosols at nuclear tests cannot be made at this time.

3.2.8 Trigger Devices

The light trigger was a modification of the one used at IVY. On Shot 1, of 14 triggers surviving the blast effects 10 worked satisfactorily. The fire destroyed all spare parts so the permanently damaged triggers on the capsized rafts could not be replaced or repaired. At island stations these devices operated more satisfactorily than on rafts. The electronic circuitry was improperly protected against atmospheric conditions.

A simple blast trigger designed and constructed at the site operated successfully at island and lagoon stations for megaton weapons but was not sensitive enough for low yield weapons. Further development of this type of trigger is indicated for future field operations.

3.2.9 Gamma Time-intensity Recorder

This device was the same type as those used in large numbers on the YAG's in Project 6.4. Two stations were operating before Shot 1. The one on Yoke was damaged by a water wave which occurred after that shot. The station on How operated satisfactorily throughout the operation until it was destroyed by a wave after Shot 5. It collected valuable information concerning time and rate of arrival of fallout and its decay. The damaged equipment was repaired and placed on Janet in preparation for Shot Echo and later moved to Leroy. It did not record any activity after Shot 6 because no fallout arrived on that island. A more complete evaluation of this type of instrument will be found in the Project 6.4 final report.[12]

[redacted]

CHAPTER 4

SAMPLE ANALYSES AND DATA REDUCTION

4.1 SAMPLE ANALYSIS

Basic analysis consisted of gamma counting those samples collected for the determination of fallout contours and measuring the fallout particle size distribution and the apparent density of the particles.

4.1.1 Counting Technique

Two instruments were employed in counting samples. The 4π gamma ionization chamber was used where conversion of measured activities to gamma field intensities was desired. The gamma scintillation counter was used where relative levels of activity were desired.

The 4π gamma ionization chamber and its calibration are identical to that described in AECD-2367. This instrument consists of a pressurized ion chamber, vibrating reed electrometer, and a Brown millivolt recorder. The chamber is filled with argon at a pressure of 600 psig and operates at a collection potential of 600 v. For low background the assembly is lead-shielded. Samples are lowered into the center of the chamber. Because the position of the source material is not critical, activities of large volumes of either liquid or solid samples can be measured. The gamma ionization chamber readings were converted arbitrarily from millivolts to mr/hr in order that all readings taken on fallout be expressed on a conventional basis. A relationship between the chamber readings in mv and a calibrated AN/PDR-T1B Survey meter was determined. Corresponding readings of 15 randomly chosen samples from Shot 1 were taken by both instruments. The equation of the resulting linear plot showed

$$mr/hr = \frac{mv}{5.19} .$$

With this relationship determined from samples of high levels of activity conversion of samples of low activity, accurately measured in the 4π ion chamber, readings could then be reliably converted to equivalent mr/hr.

The scintillation counter[18] consists of a detector assembly and

[redacted]

scaler unit Radiac Computer Indicator CP-79/UD (NavShips 91892). The detector assembly mounted inside a commercial lead castle consists of a cylindrical sodium iodide crystal 1.5 in. in diameter and 0.5 in. thick, an RCA 5819 photomultiplier tube, and a pre-amplifier unit. The crystal is shielded from the sample chamber by 0.25 in. of aluminum.

The counters used were completely evaluated for coincidence loss by using six paired sources and employing a least square evaluation.9/ Coincidence loss varied from 1 per cent at 100,000 c/m to 10 per cent at 2,000,000 c/m.

All differential fallout collections were counted under fixed geometry and corrected for background and counter coincidence losses. No attempt was made to obtain any more than relative counts between samples.

4.1.1.1 Total Collectors

Many of the total collectors contained considerable quantities of rain water which fell during the relatively long period between placement and recovery of the instruments but not during the period of fallout. In these cases there was leaching of the fallout activity into the liquid.

Preliminary separations of the liquids and solids were achieved by decanting the gross samples. Final separations were then obtained by centrifuging which left the resulting liquid clear or, in some cases, containing colloids.

The liquid volumes were measured and the solids dried and weighed. The samples were placed in 100-ml lusteroid centrifuge tubes and gamma activity measurements were made on these samples with a 4π gamma ionization chamber. In instances where the liquid fraction exceeded 100 ml, these samples were concentrated to the desired volume after acidification.

4.1.1.2 Gummed Paper Collectors

The acetate-backed 1-ft squares of gummed paper were removed from their cardboard mounts and folded to fit into 100-ml lusteroid tubes. Their gamma activities were measured with a 4π gamma ionization chamber.

4.1.1.3 Differential Fallout Collectors

Each of the 40 polyethylene collecting jars was removed from the collector and decontaminated on the outside. The jar openings were then capped with cellophane 0.001 in. thick held in position with a rubber band. Gamma counts were then made with a scintillation counter.

4.1.2 Particle Size Measurements

The particles were fixed with Krylon on a framed cellophane membrane. Contact autoradiographs were made using Eastman Commercial Ortho film. The outer island analysis employed nuclear emulsion stripping film with the particles fixed to the non-emulsion side of the film

[redacted]

with Krylon. Use of nuclear emulsion stripping film is the better technique. However, because of the unavailability of the stripping film, the majority of the work was done using the autoradiographic techniques described above.

All diameter measurements were made on one axis only using an optical microscope with a micrometer eyepiece. The least count of the micrometer was 2μ.

Each plate was scanned and measurements on the radioactive particles were recorded. The minimum diameter of particles measured in this analysis was of the order of 5 μ.

4.1.3 Particle Density Measurements

An optical microscope having a calibrated micrometer eyepiece was used to measure particle diameters along 2 axes. Relative activities were determined with a gamma scintillation counter under conditions identical to those used in counting the gross samples from the differential fallout collector.

Particle density was determined by a flotation method with mixtures of bromobenzene and bromoform as the liquid phase. In a liquid system containing only two components, the densities and refractive index values are an additive function of the compositions. Corresponding densities and index of refraction with composition are available from the literature. Pure bromobenzene has a density of 1.499 and an index of refraction of 1.560 while pure bromoform has a density of 2.890 and an index of refraction of 1.598.

Each particle was placed in a precision 1-ml glass-stoppered volumetric flask half filled with a solution of density approximating 2. Inverting the flask allowed vertical movement of the particle along the flask stem. Drops of the appropriate liquid then were added and mixed until vertical movement of the particle ceased, indicating that the densities of the liquid and particle were identical. An Abbe refractometer was used to determine the index of refraction of the resulting liquid and hence its density from the known relationships.

4.2 DATA REDUCTION

Equation 2.1 implied a constant ratio between the measured sample activity and the infinite gamma field at the sampling station. This implication was found to be valid only for the gummed paper collectors. The ratio was not constant when applied to the total collectors.

4.2.1 Total Collectors

All measurements of gamma activity were made in the 4π ionization chamber. Appendix B tabulates all data as measured. Where activity in the total collectors was found to exist in both the liquid and solid phases the total activity for that collector was determined by simply adding the liquid and solid phase measured values. The data from the land stations, after being converted to equivalent mr/hr values, were compared to the equivalent field survey data obtained by both Task Force

[redacted]

Rad Safe surveys and Project 2.5a surveys. Comparisons of these values were done by converting all measurements to mr/hr at 0 + 4 days after the detonations. This period was selected because these island survey measurements were felt to be more valid than at earlier times when the majority of the survey readings were obtained by helicopter at various heights above the surface. Conversion of all measurements to 0 + 4 days was made by using the composite gamma field decay curve in Fig. 5.1. Although this decay curve was constructed from both theoretical and experimental evaluation of Shot 1 data, its use in reducing data from Shots 2,3,4, and 5 does not introduce appreciable error as is shown by a comparison of the experimental and theoretical decay curves for these shots.13/ It does introduce some error into the Shot 6 calculations because of the significantly different capture to fission ratios existing for Shot 6.

The ratio of actual gamma fields to measured activity found in the total collectors located on the atoll islands was not a constant for the many islands evaluated. Figure 4.1, a plot of field readings to readings as determined from the total collectors, was constructed by considering all data that were available; this included measurements from Shots 1,3,4, and 6. A curve was fitted to the data which indicated a 1 to 1 ratio at high levels of activity and a 10 to 1 ratio where the total collector measurements were of low intensity. This curve was extrapolated at total collector levels below 1.0 mr/hr with a constant slope indicating a 10 to 1 ratio between field survey measurements and total collector measurements. Since this variable ratio was found to be independent of the shot detonated, it is reasonable to believe that the explanation for the variance is inherent in the characteristics of the collecting instrument.

The fallout in areas of high residual gamma activity were those where the larger particles predominated. These particles with comparatively high rates of fall apparently do not tend to follow the streamlines about the collector. This tendency may explain the higher collecting efficiency resulting in those areas of high residual gamma fields. The fact that the ratio of gamma field measurements to gamma measurements from the total collector approaches 1 in the areas of high gamma activity is fortuitously coincidental.

The activity collected in the total collectors employed at the lagoon stations was converted to equivalent infinite field values by using the curve in Fig. 4.1.

All data were then converted to r/hr at 1 hr using the composite gamma decay curve in Fig. 5.3.

A similar evaluation of the gummed paper collectors was made. The curve in Fig. 4.2 was constructed using data from Shots 1, 3, and 6 to determine the ratio of gamma infinite field measurements made with survey instruments to those made on the gummed papers with the 4π gamma ionization chamber. A constant ratio of 2 to 1 was determined for this collecting device.

The gummed paper measurements from lagoon and free-floating sea stations were then corrected to infinite field values at 0 + 4 days by use of Fig. 4.2 and then converted to r/hr at 1 hr using the composite gamma decay curve in Fig. 5.3.

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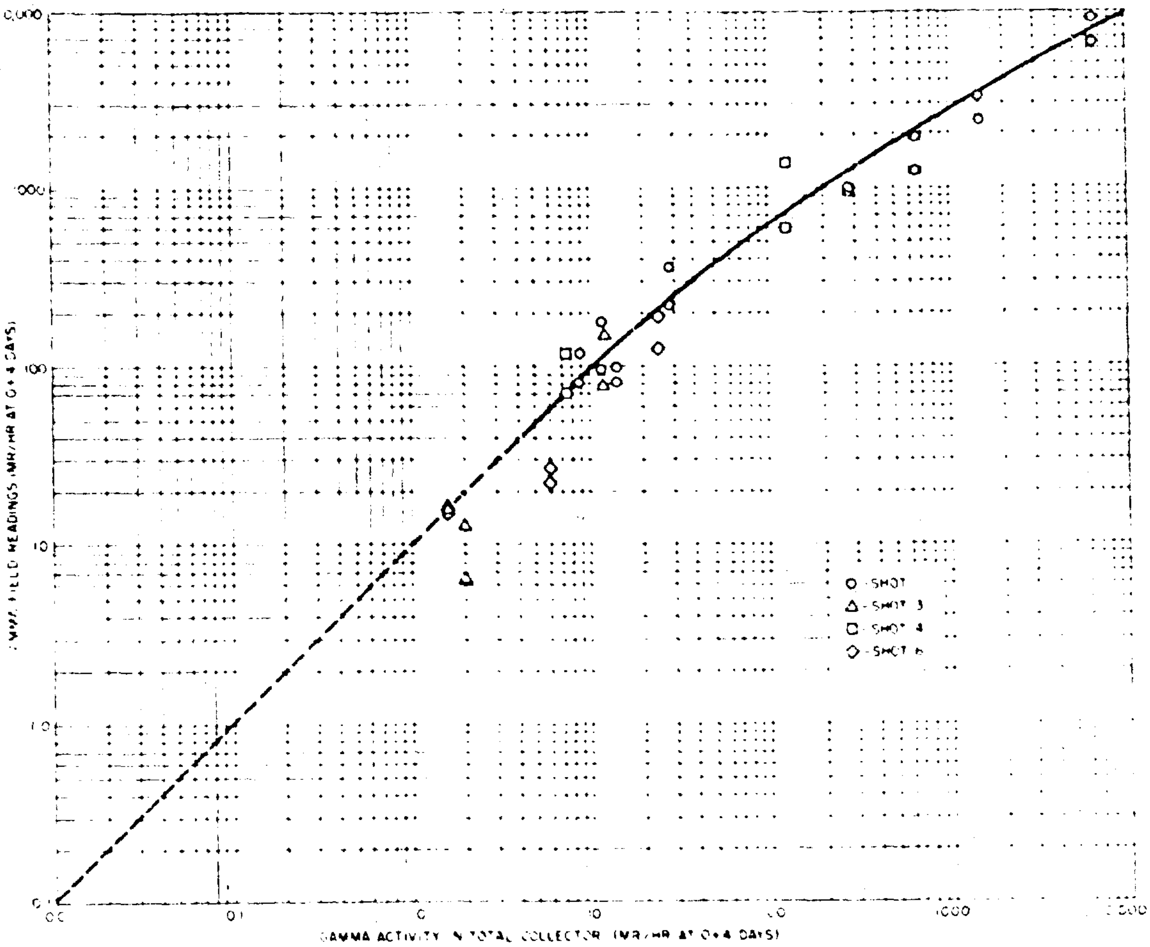

Fig. 4.1 Ratio of Gamma Infinite Field Measurements to Equivalent Gamma Measurements From the Total Collector (mr/hr at 0 + 4 days)

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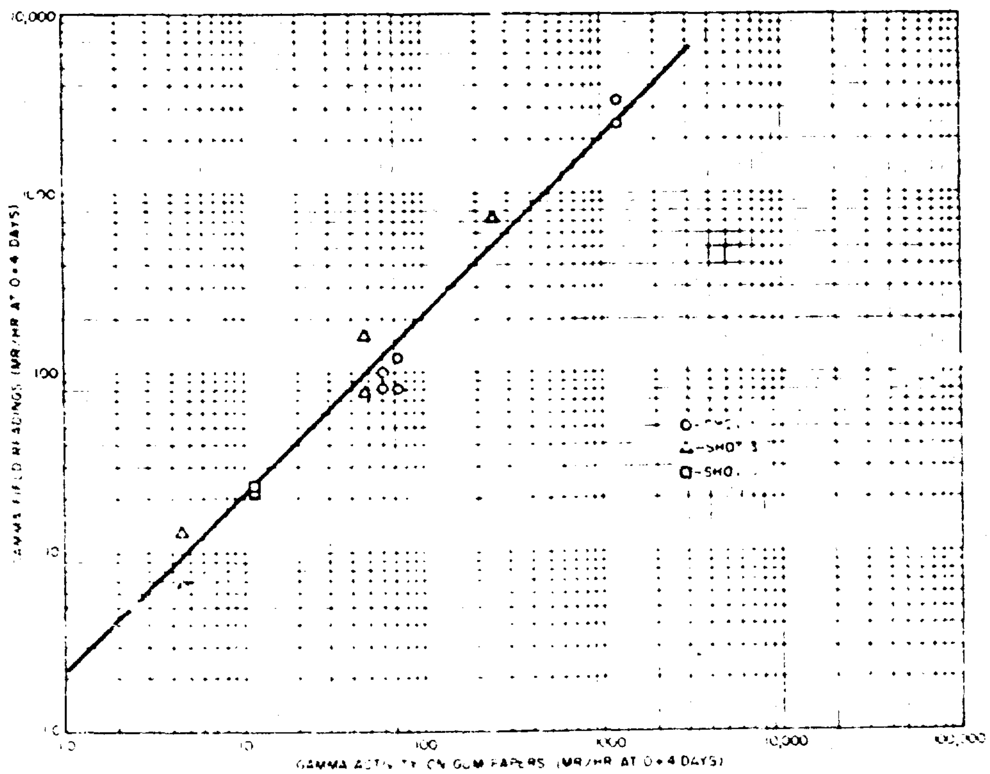

Fig. 4.2 Ratio of Gamma Infinite Field Measurements to Equivalent Gamma Measurements from the Gummed Paper Collector (mr/hr at 0 + 4 days)

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CHAPTER 5

CHARACTERISTICS OF FALLOUT

5.1 GAMMA FIELD DECAY

The decay rate for the gamma radiation from the fallout as measured in the field was analyzed from a theoretical as well as an experimental viewpoint. Data are presented on decay for Shots 1, 2, and 3. Since the capture to fission ratios have been reported as substantially the same for Shots 1 through 5* these data should be applicable to all five detonations. Their use on Shot 6 radioactive debris may be questionable. In general, the laboratory samples measured with ionization instruments in this study compare well with the field data read with an ionization survey meter, AN/PDR-71B.

The standard gamma decay constant, k = 1.2, that is presently used for nuclear detonations, is invalid for thermonuclear devices over the period from time zero until the contribution from induced activities is insignificant as is evidenced by the following analysis.

5.1.1 Theoretical and Field Decay

Theoretical beta (d/m) decay curves (Fig. 5.1) were constructed for Mike shot, IVY** as well as for Shot 1, CASTLE.*** Data for these curves were calculated from the fission product decay and the reported capture to fission ratios of the important nuclides and were normalized to 10,000 fissions at 0 time.18/ A theoretical gamma decay curve based on the capture to fission ratios from Shot 1 (Fig. 5.2) was also constructed. The calculated curve gives the gamma energy emission rate (Mev/min) from a radioactive source of Shot 1 composition as a function of time after detonation. It will correspond to the experimental gamma ionization decay curve if (a) the detector response is independent of energy (flat) at all gamma energies and (b) the geometry of the source,

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* Private communication with N. Ballou, U DL.

** By N. Ballou, USNRDL.

*** By R. Cole, USNRDL.

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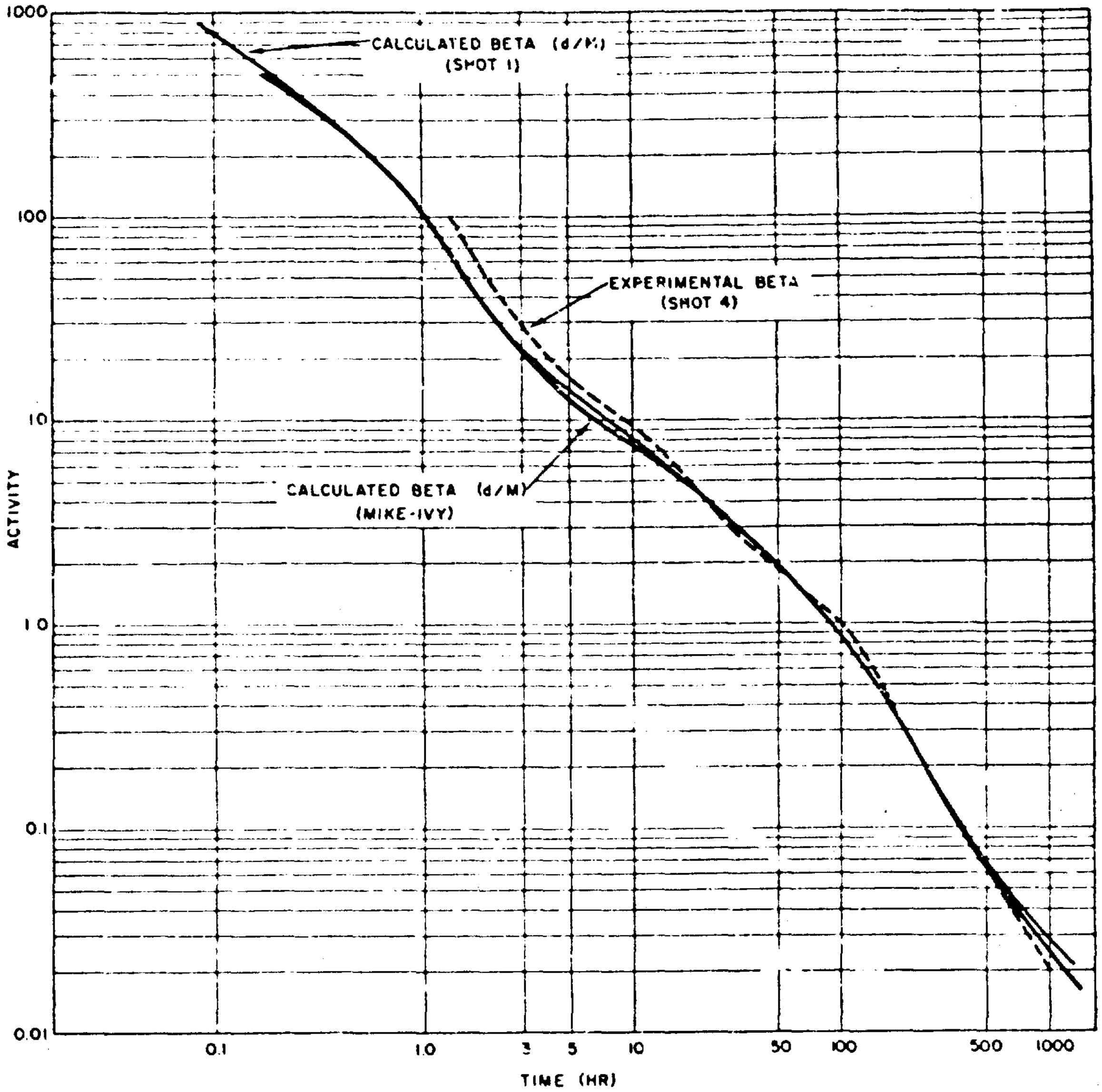

Fig. 5.1 Experimental and Calculated Beta Decay Curves

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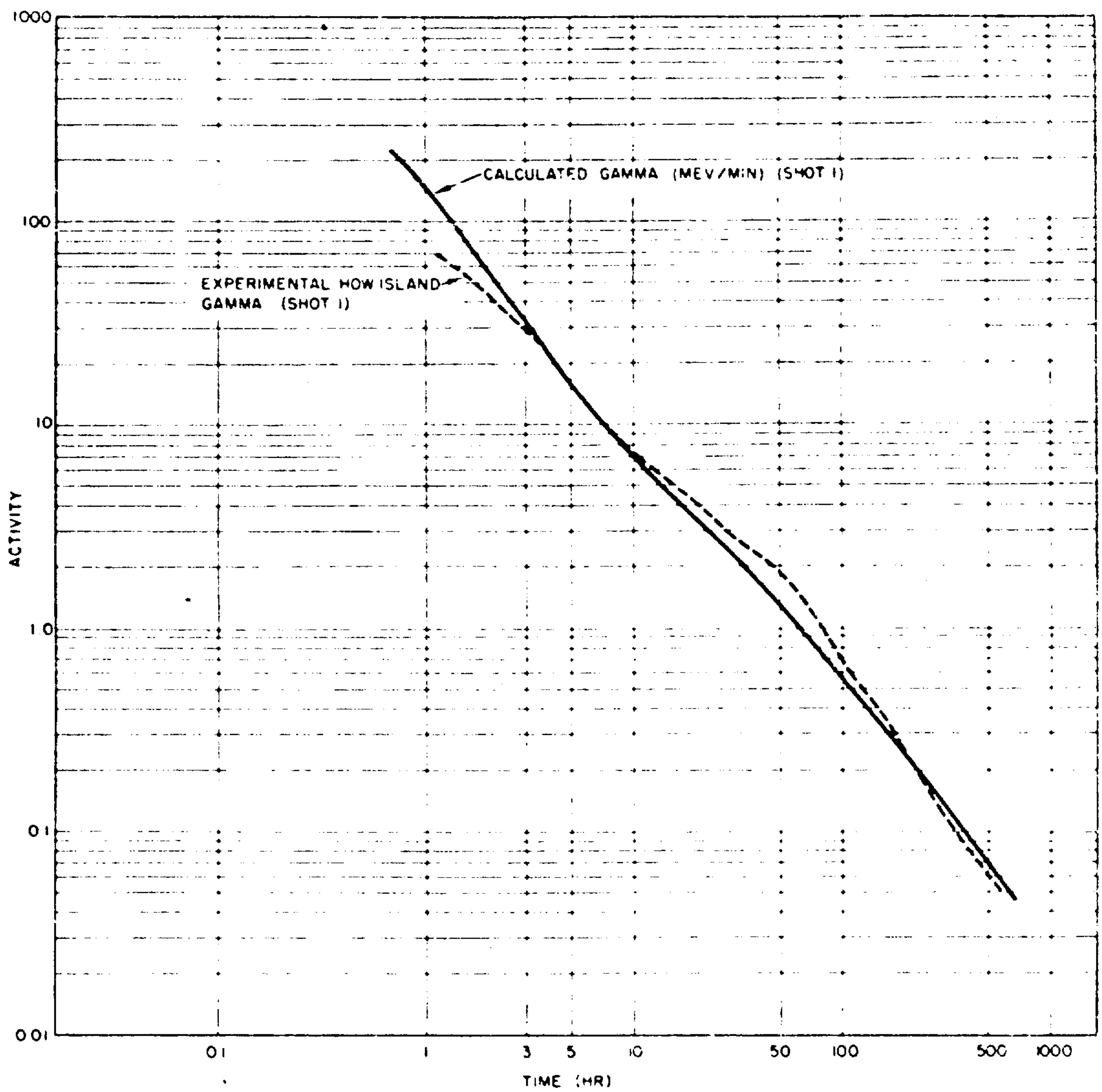

Fig. 5.2 Calculated Gamma Decay Curve and Experimental Gamma Ionization Decay Curve for Shot 1

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scattering, and absorption do not affect the detector response or gamma spectrum seen by the detector. Since the latter condition is never fully satisfied, the calculated curve always differs from the experimental one. Table 5.1 tabulates the slopes of the theoretical decay curves considered. The experimental beta decay curve for Shot 4 (Fig. 5.1) and the experimental gamma ionization decay curve (Fig. 5.2) for Shot 1 are presented for comparison. The two theoretical beta decay curves are in very close agreement and each agree well with the experimental beta decay curve. The experimental gamma ionization decay curve for Shot 1 and the calculated gamma (Mev/min) decay curve (Fig. 5.2) are not in good agreement from 5 to 100 hr after detonation. This lack of agreement may be due to the nature of the response of the ionization instrument or to other factors.

TABLE 5.1 - Theoretical Decay Data

Type of Decay	Slope of Decay Curve over Period Indicated (hr after ABD)					
	1 - 3	1 - 5	3 - 48	5 - 96	24 - 1440	96 - 672
Calculated gamma ionization decay -- Shot 1 (Mev/min)		1.37		1.08		1.33
Calculated beta decay -- Shot 1 (d/m)	1.42		0.83		1.40	
Calculated beta decay -- Mike Shot, IVY (d/m)	1.44		0.865		1.37	

Figure 5.3 is a composite gamma ionization decay curve constructed from all available field data; it has been used in this report for conversion of all field data taken with an AN/PDR-T1B, AN/PDR/39, or the gamma ionization time-intensity recorders as well as for conversion of the 4π gamma ionization chamber laboratory data. Comparison of How Island Task Force Rad Safe measurements and the Project 2.5a gamma time-intensity measurements shows very close agreement from 0 + 2 to 0 + 20 days after Shot 1 (Table 5.2).

This agreement of the time-intensity recorder curve with field survey readings was assumed to hold between 0 + 3 hr and 0 + 2 days. Therefore, for the time interval (0 + 3 hr to 0 + 20 days) the time-intensity recorder data were used to construct the composite curve (Fig. 5.3). However, for the interval from 0 + 1 hr to 0 + 3 hr the gamma time-intensity recorder must be compensated for fallout that was still arriving; the compensated curve would then have a slope steeper than the experimental decay curve. For this interval (0 + 1 hr to 0 + 3 hr) the calculated gamma decay curve was used in the construction of this composite decay curve.

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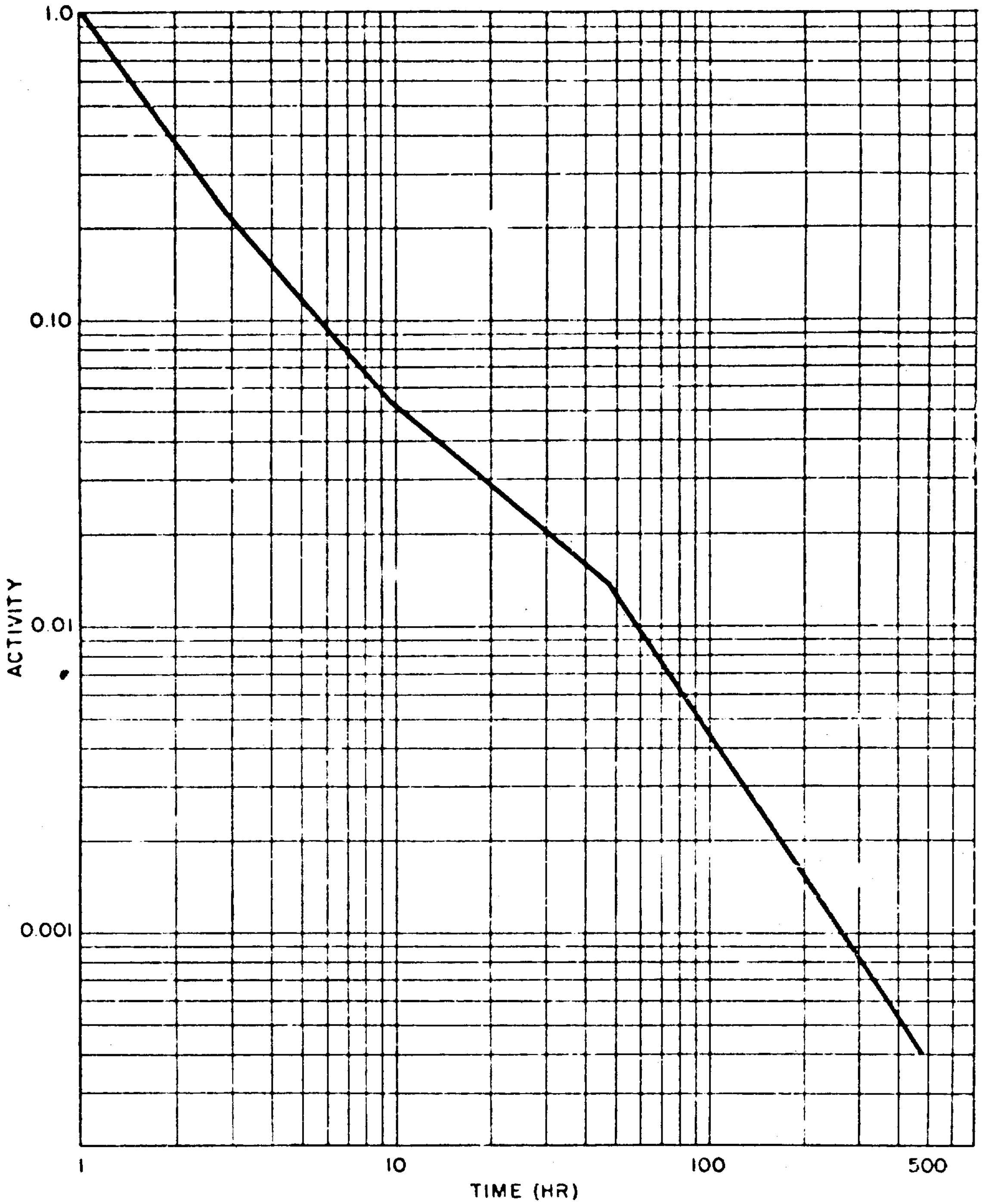


Fig. 5.3 Composite Gamma Ionization Decay Curve

TABLE 5.2 - Experimental Field Decay Data

Type of Decay	Slope of Decay Curve over Period Indicated (hr after ABD)		
	3 - 10	10 - 48	48 - 480
Gamma Ionization Time-Intensity Recorder, How Island-Shot 1	1.19	0.815	1.52
Gamma Ionization Task Force Rad Safe T1B Survey	-	-	1.50

5.1.2 Experimental Laboratory Decay

Table 5.3 summarizes the slopes of the decay curves obtained from samples measured in the laboratory on two instruments. Gamma decay was measured with a 4π gamma ionization chamber and a gamma scintillation counter. The average slope of the decay curves measured on 6 individual fallout particles with a gamma scintillation counter is -2.08 from 9 to 30 days and -1.50 from 30 to 60 days. Project 2.6a reported[18] an average slope of -2.11 for measurements with a similar gamma scintillation counter on the first four shots from total collector samples over the period 0 + 7 to 0 + 22 days. The decay curve slopes obtained from measurements on the 4π gamma ionization chamber are of more general interest since its response is close to that of the AN/PDR-T1B survey meter. A comparison of Samples 1, 18, and 21 (Table 5.3) shows that the decay curves of these fallout samples have comparable slopes; however, the liquid fraction of Sample 18 has a slope of -1.22 while the solid fraction has a slope -1.60. The ionization-counted gummed paper samples from Shot 2 have an average slope of -1.61 from 170 to 480 hr; for Shot 3 samples the slope was -1.73 from 200 to 600 hr. These slopes suggest that the leaching of activity preferentially removed the longer lived nuclides both in the case of Sample 18, Shot 3 and the rain- and sea-washed gummed papers from Shots 2 and 3. It further suggests that the gummed paper collectors lost a portion of their collected fallout from leaching by sea spray and rain.

The data are consistent with little fractionation of activity within the sampling area.

5.2 PARTICLE SIZE

Fallout particles from the differential fallout collector were analyzed for size distribution with respect to both time and distance. Data are presented primarily for Shot 1 with limited data on Shot 6. The amount of visible particulate collected after Shots 2, 4, and 5 was

[redacted]

TABLE 5.3 - Experimental Laboratory Decay Data

Sample No.	Type of Decay	Slope of Decay Curve over Period Indicated (hr after ABD)								
		170 to 480	200 to 600	216 to 600	216 to 720	264 to 1440	300 to 900	600 to 1440	720 to 1440	900 to 1700
1	Solid sample - station 251.07 Shot 1 (4π Gamma Ionization Counted)						1.34			1.16
2	Individual particle - station 250.04 Shot 1 (Gamma Scintillation Counted)				2.25				1.80	
3	Individual particle - station 250.04 Shot 1 (Gamma Scintillation Counted)			1.90				1.50		
4	Individual particle - station 250.04 Shot 1 (Gamma Scintillation Counted)					1.75				
5	Individual particle - station 251.03 Shot 1 (Gamma Scintillation Counted)				2.20				1.40	
6	Individual Particle - station 250.24 Shot 1 (Gamma Scintillation Counted)				2.45				1.50	
7	Individual particle - station 251.10 Shot 1 (Gamma Scintillation Counted)				1.95				1.10	
	Gummed Paper Samples									
8	Sample T_4 Shot 2 (4π Gamma Ionization Counted)	1.82								
9	Sample T_4 Shot 2 (4π Gamma Ionization Counted)	1.85								

TABLE 5.3 - Experimental Laboratory Decay Data (Cont.)

Sample No.	Type of Decay	Slope of Decay Curve over Period Indicated (hr after ABD) 170 to 480	200 to 600	216 to 600	216 to 720	264 to 1440	300 to 900	600 to 1440	720 to 1440	900 to 1700
	Gummed Paper Samples (Cont.)									
10	Sample A_4 Shot 2 (4π Gamma Ionization Counted)	1.70								
11	Sample A_4 Shot 2 (4π Gamma Ionization Counted)	1.64								
12	Sample P_4 Shot 2 (4π Gamma Ionization Counted)	1.51								
13	Sample Q_4 Shot 2 (4π Gamma Ionization Counted)	1.68								
14	Sample O_4 Shot 2 (4π Gamma Ionization Counted)	1.38								
15	Sample 250.18-1 Shot 3 (4π Gamma Ionization Counted)		1.77							
16	Sample 250.17 Shot 3 (4π Gamma Ionization Counted)		1.64							
17	Sample 250.18-2 Shot 3 (4π Gamma Ionization Counted)		1.77							

[redacted]

TABLE 5.3 - Experimental Laboratory Decay Data (Cont.)

Sample No.	Type of Decay	Slope of Decay Curve over Period Indicated (hr after ABD)								
		170 to 480	200 to 600	216 to 600	216 to 720	264 to 1440	300 to 900	600 to 1440	720 to 1440	900 to 1700
	Total Collector Samples									
18	Sample 250.18 Shot 3 (4π Gamma Ionization Counted)		1.30							
19	Sample 250.18 (Liquid Fraction) Shot 3 (4π Gamma Ionization Counted)		1.22							
20	Sample 250.18 (Solid Fraction) Shot 3 (4π Gamma Ionization Counted)		1.60							
21	Sample 250.06 Shot 3 (4π Gamma Ionization Counted)		1.33							

[redacted] A

small. No samples suitable for particle analysis were obtained from Shot 3. Following Shot 1, 6971 radioactive particles were analyzed from the area within the Bikini Atoll and 621 particles collected on the outer atolls of Ailinginae, Rongelap, and Utirik were evaluated. The differential fallout collector on the island of Alice contained some particulate from Shot 6. These data are also presented.

5.2.1 Shot 1, Close-in Fallout

The size distribution of close-in fallout particles with respect to time for four lagoon and three island stations are given in Appendix C. Only radioactive particles are included in the data. Of the 40 available sampling increments within each differential collector, those increments that visually appeared to contain a large amount of particulate were selected for analysis. Increments over a wide time period were likewise selected. Analysis of the bar graphs with respect to rate of arrival or time of arrival is therefore an approximation. Data on time of arrival are presented in Section 5.6 of this report.

Figure 5.4 shows the size frequency distribution of the Shot 1 close-in particulate. It is a composite of the bar graphs for the four lagoon and three island stations. (Figs. C-1 through C-7.)

Figure 5.5 is a plot of the cumulative size distribution of Shot 1 particulate presented on a log probability graph. The size distribution is very close to log normal with a geometric mean particle diameter of 112 μ.

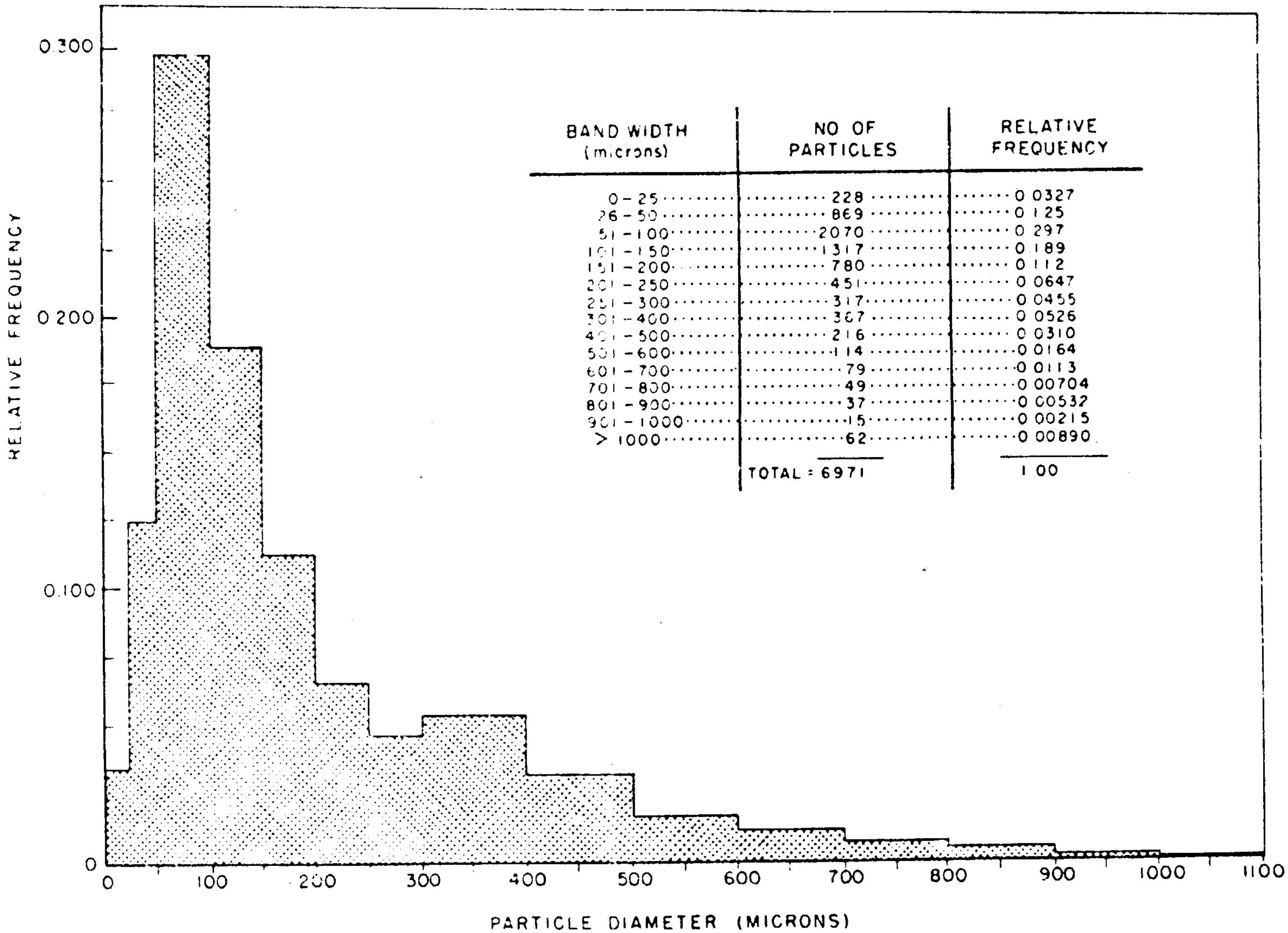
5.2.2 Shot 1, Outer Island Fallout

Samples of earth were collected by the outer island survey team following Shot 1.[15] The radioactive particulate found in these soil samples was analyzed for size distribution and the results are presented in Fig. 5.6. These atolls were 70 to 280 nautical miles from Shot 1. Figure 5.7 shows a log normal size distribution for particles collected on three atolls. The geometric mean particle diameters are presented in Table 5.4.

TABLE 5.4 - Geometric Mean Particle Diameter

Atoll	Distance from Shot Point (n mi)	Geometric Mean Particle Diameter (μ)
Bikini	10	112
Ailinginae	70	60
Rongelap	107	70
Utirik	277	45

[redacted]



BAND WIDTH (microns)	NO OF PARTICLES	RELATIVE FREQUENCY
0 - 25	228	0 0327
26 - 50	869	0 125
51 - 100	2070	0 297
101 - 150	1317	0 189
151 - 200	780	0 112
201 - 250	451	0 0647
251 - 300	317	0 0455
301 - 400	367	0 0526
401 - 500	216	0 0310
501 - 600	114	0 0164
601 - 700	79	0 0113
701 - 800	49	0 00704
801 - 900	37	0 00532
901 - 1000	15	0 00215
> 1000	62	0 00890
	TOTAL = 6971	1 00

Fig. 5.4 Shot 1, Composite Particle Size Distribution

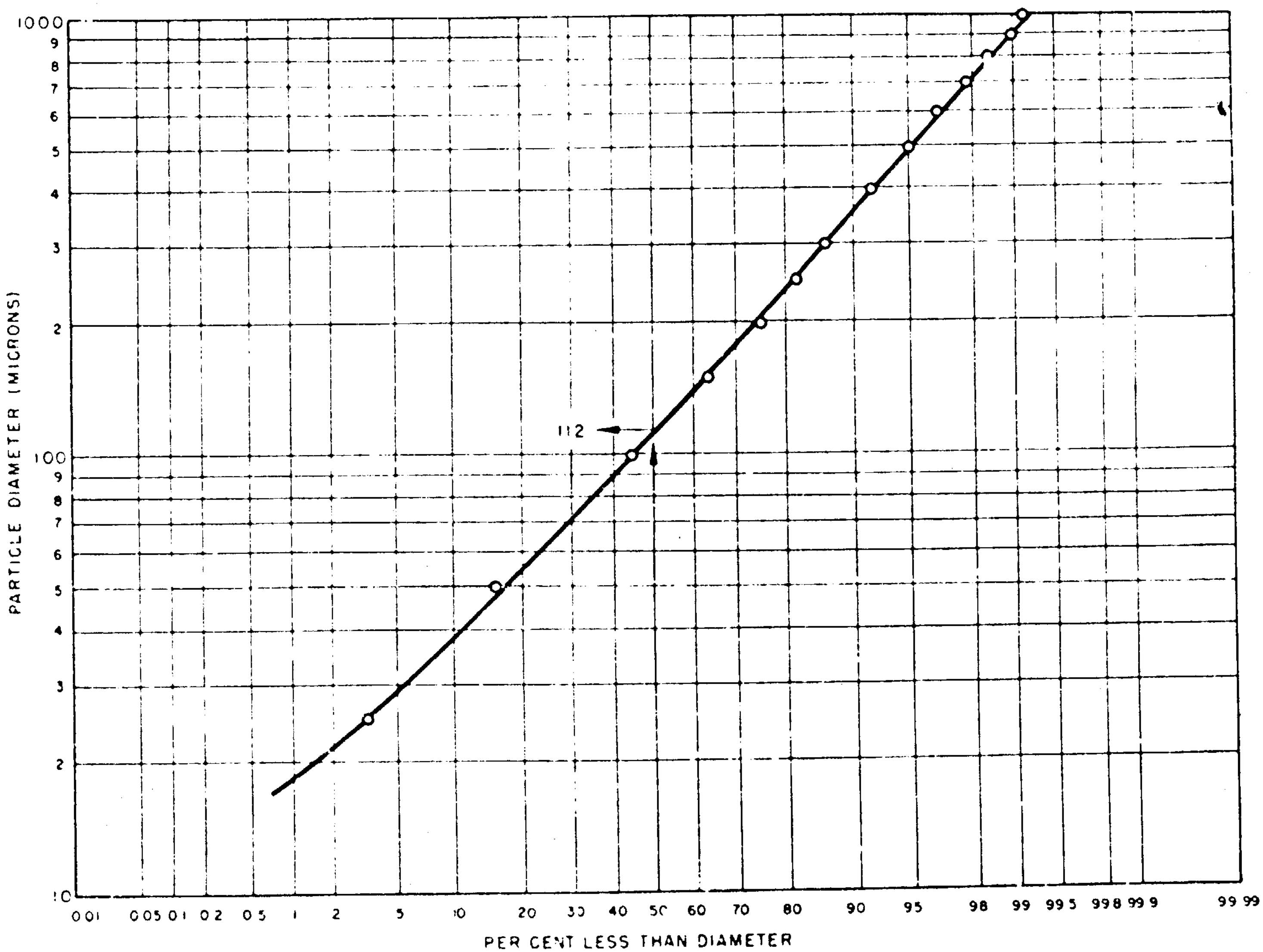


Fig. 5.5 Shot 1, Cumulative Particle Size Distribution

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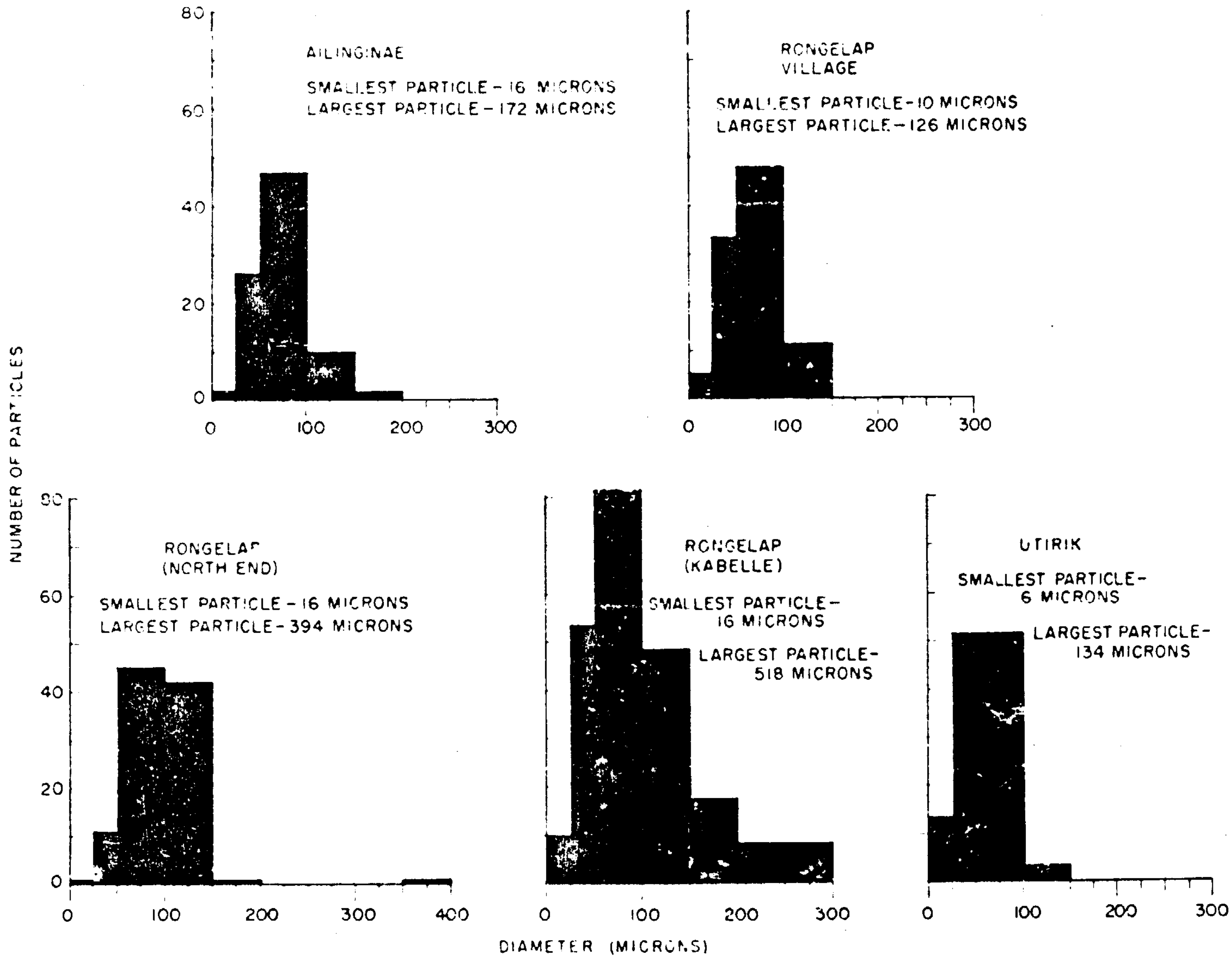

Fig. 5.6 Shot 1, Outer Atoll Particle Size Distribution

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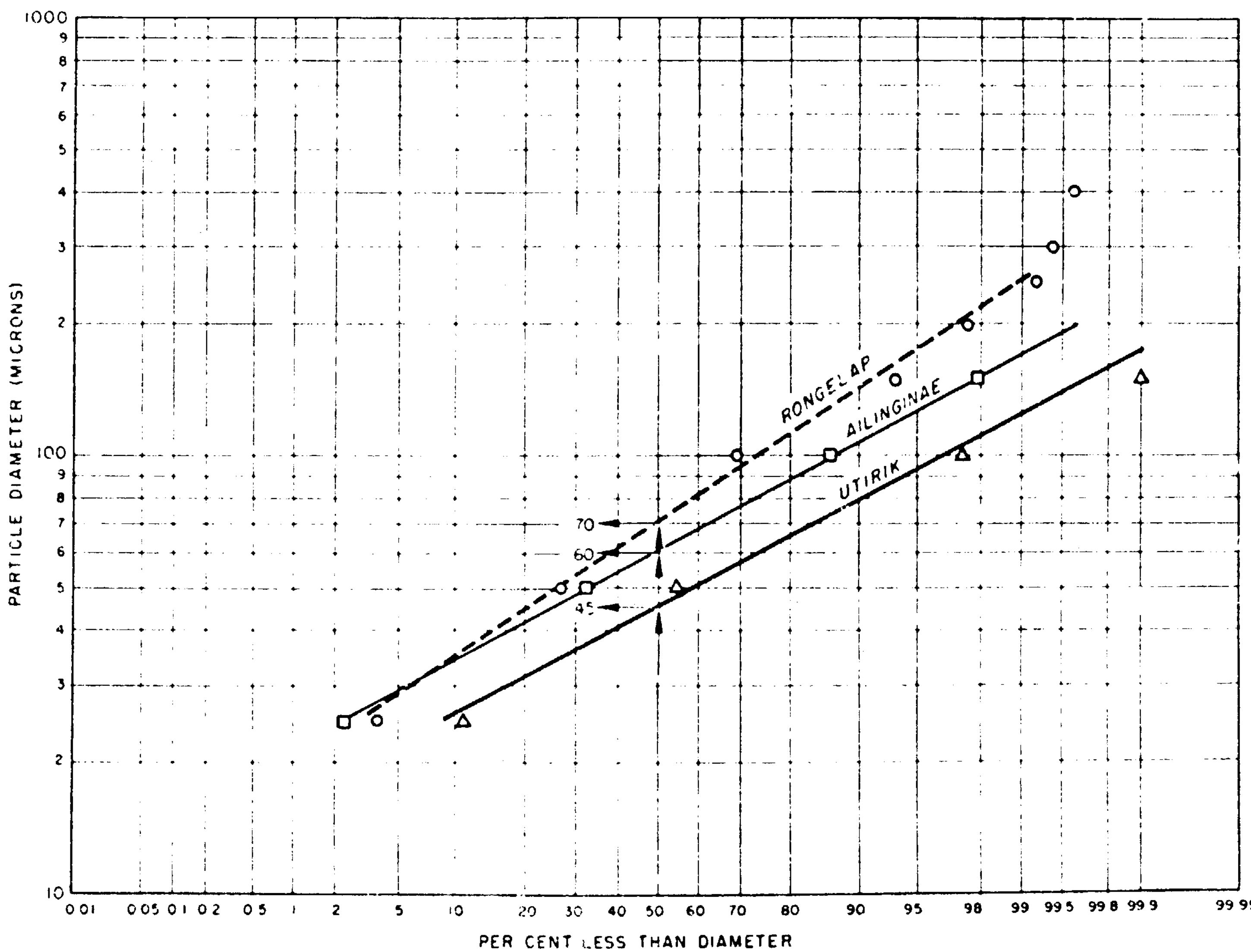

Fig. 5.7 Shot 1, Outer Atoll Cumulative Par icle Size Distribution

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The fact that the mean particle diameter at Ailinginae is smaller than at Rongelap can be partially explained by analysis of the wind profile which indicates, as one moves south from the axis of symmetry of the fallout pattern, that the particles delivered have smaller diameters (see Chapter 6).

5.2.3 Shot 6, Particle Size

The differential collector stationed on Alice contained visible particulate as well as some liquid; the analysis of particle size distribution is presented in Appendix C. With a total of 321 particles measured the distribution was nearly log normal with a geometric mean diameter of 180 μ as shown in Fig. 5.8. Alice was 3 nautical miles from ground zero.

5.3 RATIO OF ACTIVE TO INACTIVE PARTICLES

One of the most difficult problems to resolve is the ratio of active to inactive fallout particles that arrive at a collecting instrument. This is especially true of the smaller diameter particles because it is extremely difficult to avoid pollution of the sample by extraneous particulate. In this analysis many small inactive particles were observed during the measurement of particle diameters. In many cases these particles were less than 5 μ in diameter. To arrive at a ratio, all particulate was ignored that did not have the characteristic white opaque color of fallout.

Two samples were analyzed from Shot 1 fallout collected at lagoon stations where the effect of island dust pollution was minimized. The results are shown in Fig. 5.9. Approximately 25 per cent of the particles were found to be inactive with the mean particle size of the inactive particles smaller than the active.

5.4 PARTICLE DENSITY

Particles from the Shot 1 lagoon station differential fallout collectors were analyzed to determine their apparent density which is defined as the specific gravity of the particle as a whole. Because of the station locations and the collecting instrument used, these particles had a very high probability of being true fallout. Seventy-nine particles from stations 250.04, 250.17, and 250.24 were measured. Density, average diameter, color, and relative activity were determined for each particle.

Table 5.5 shows the particle density found at each station. The overall average density of the 79 particles was 2.36 g/cu cm with a standard deviation of 8.9 per cent.

Attempts to find relationships between particle size and activity; particle size and density; and density and activity proved unsuccessful. All particle density data are tabulated in Appendix D.

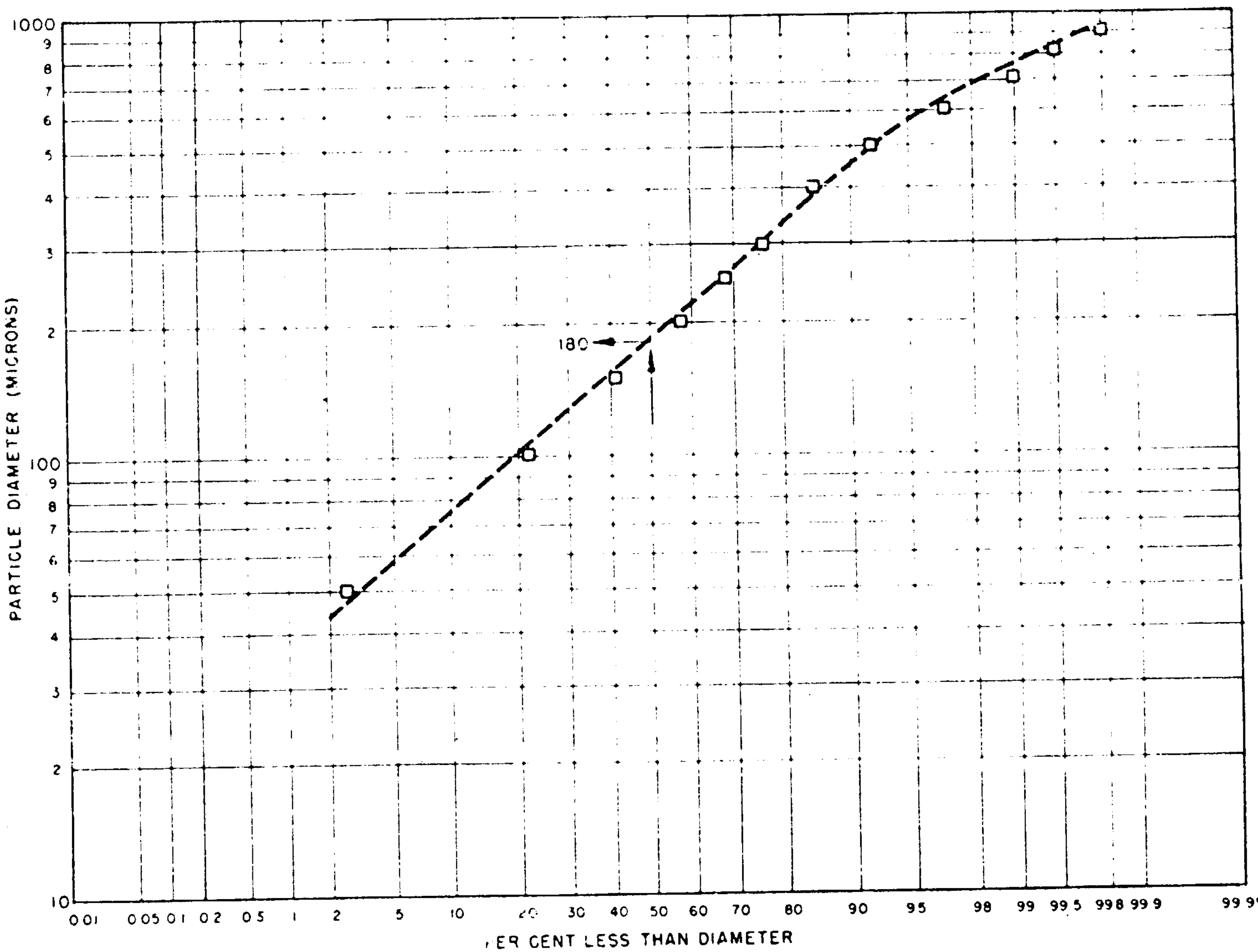

Fig. 5.8 Shot 6, Cumulative Particle Size Distribution, Station Alice

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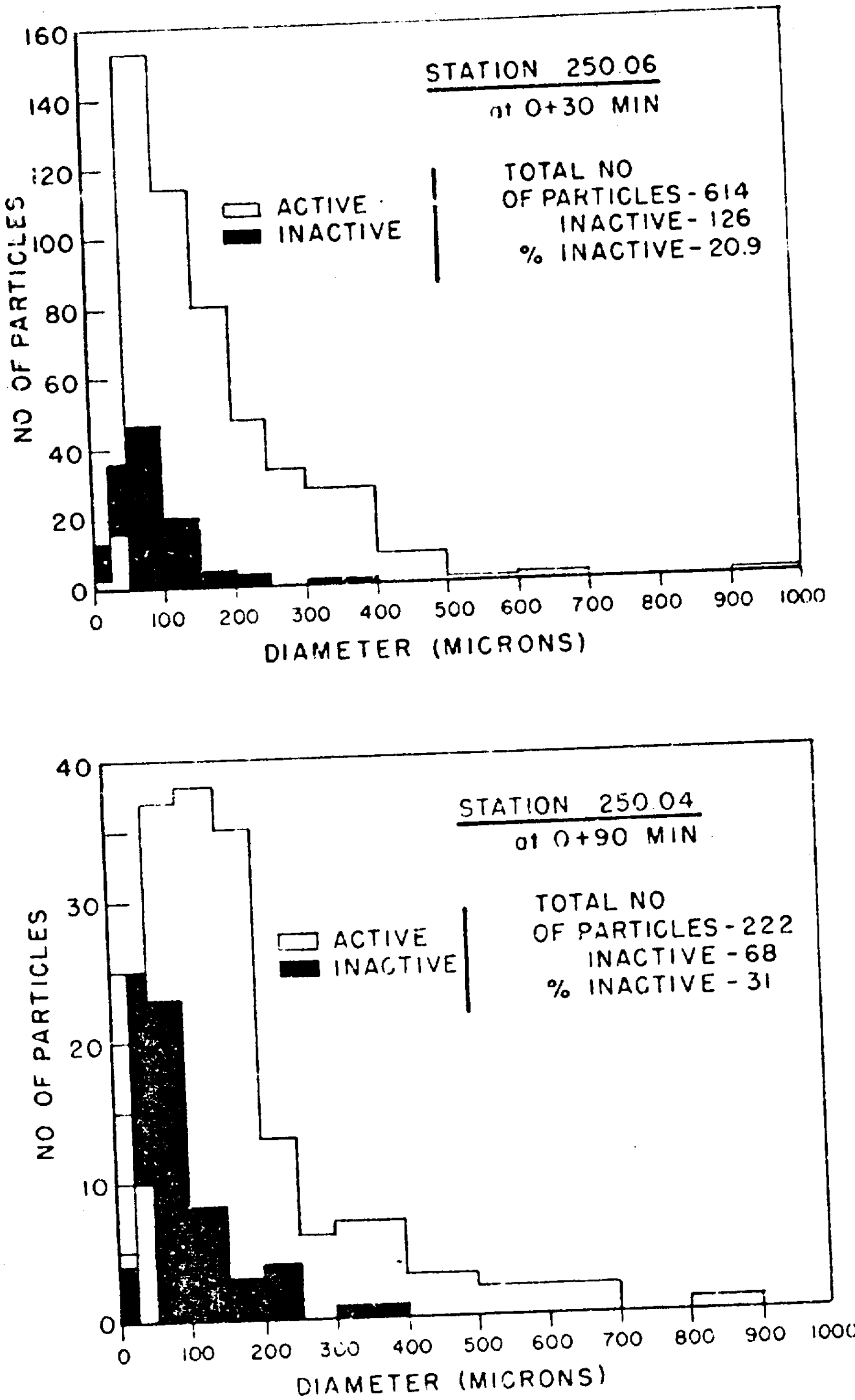

Fig. 5.9 Shot 1, Ratio of Active to Inactive Particles

[redacted]

TABLE 5.5 - Particle Density

Station	No. of Particles Investigated	Average Density (g/cu cm)	Standard Deviation (per cent)
250.04	32	2.24	9.2
250.17	29	2.40	7.4
250.24	18	2.45	7.4

5.5 GROSS PHYSICAL CHARACTERISTICS OF FALLOUT

Comprehensive date on physical and chemical characteristics of fallout are presented in the Project 2.6a report.[18]

5.5.1 Surface Land Shots

It is well established that the fallout from the island shots was very similar to that which occurred after Mike shot at IVY, namely dry, white, opaque, irregularly shaped particles. Figure 5.10 shows Shot 1 fallout as it arrived on the gummed paper collector located at station 250.04. It is typical of fallout from island detonations in the Pacific Proving Ground.

5.5.2 Surface Water Shots

Positive evidence of particulate fallout was found in the differential collector located at Alice Island after Shot 6. However, the gummed paper collectors located on the free floating buoys after Shot 2 showed no evidence of any particles visible to the naked eye. It is felt by some observers that the fallout from the surface water detonations was primarily in the form of a mist or aerosol. This is substantiated to some degree by the observation of the identification flags located on the sea stations after Shot 2. These flags were highly radioactive, many times more active than the total collectors of the same station. It is reasonable to assume that a moist fine fallout would be absorbed by the flapping flags much more easily than would a dry particulate.

5.6 TIME OF ARRIVAL OF FALLOUT

The primary instrument for determining the period over which fallout took place was the differential fallout collector. Information on time of arrival was also obtained from the gamma time-intensity recorder stationed on How Island; further information may be obtained from time-intensity recorders operated by Project 2.2. Also, limited evidence of arrival time is available from the Task Force Ship's logs and Project 6.4.

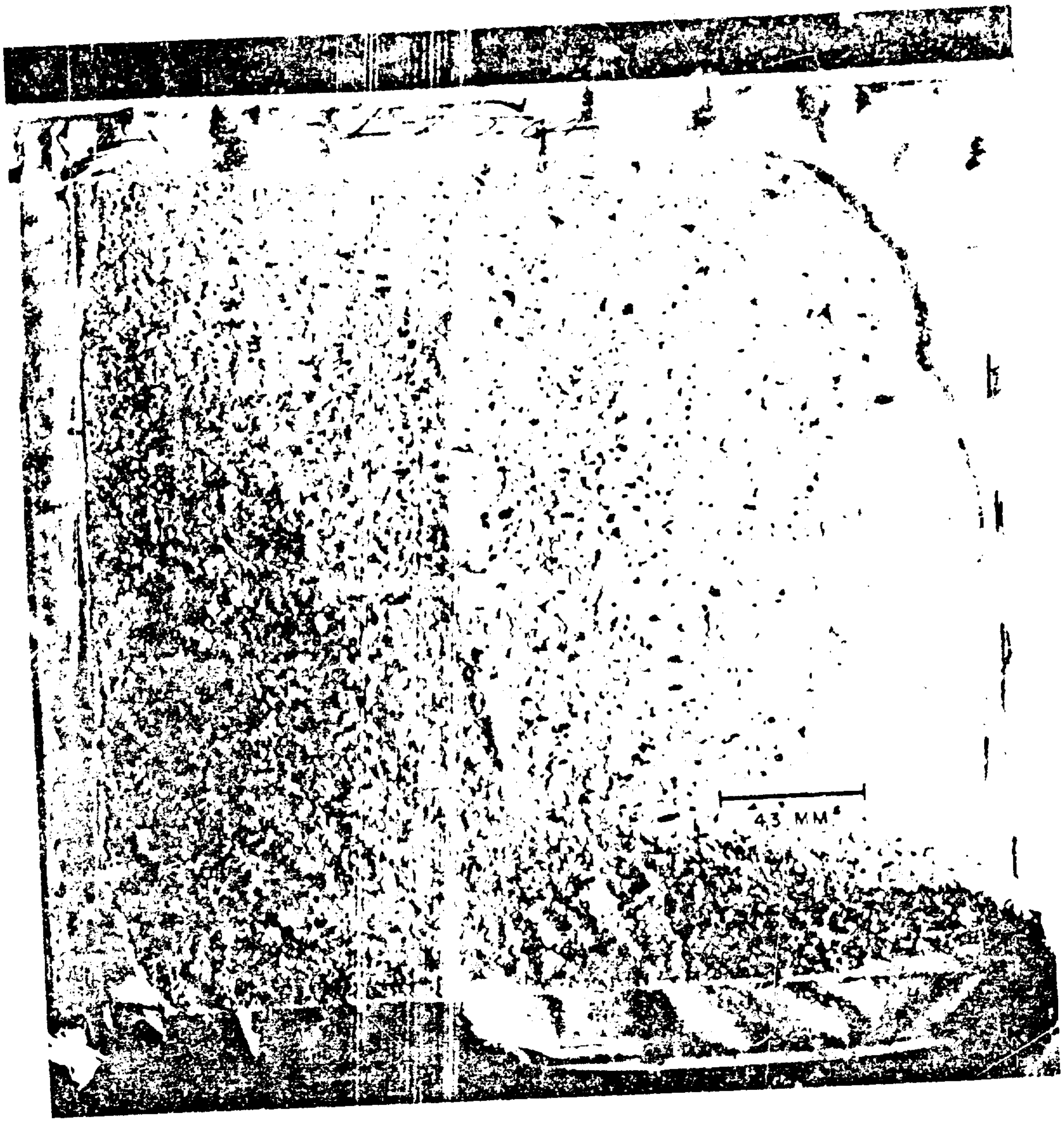

Fig. 5.10 Shot 1, Fallout Particulate, Station 250.04

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5.6.1 Shot 1

Fourteen differential fallout collectors were recovered from the land and lagoon stations after Shot 1. Of these, eight had sampled properly and the data therefrom are presented in Appendix C (Figs. C-9 through C-16). Of the 40 sampling increments, Samples 10 and 11, 20 and 21, and 30 and 31 were collected over the same time interval (see points A,B, and C of Figs. C-9 through C-16.) With perfect sampling these increments would collect identical amounts of fallout and the reduced data could then be used to determine not only the period of fallout but also the rate of arrival. However, as indicated from increment groups A,B, and C, the levels of activity varied by as much as an order of magnitude. This variation was undoubtedly the result of sampling small amounts of material over a small area for short time intervals. This deficiency does not affect the usefulness of the instrument in performing its primary function of determining the time of arrival but it does explain the erratic nature of the curves. Relative counts of each increment were made with a gamma scintillation counter under fixed geometry. The level of activity as indicated in Figs. C-9 through C-16 should not be construed as indicative of the rate of arrival of fallout material.

Several differential fallout collectors that failed to trigger were analyzed to determine the field background of the collecting increments. Figure C-17 shows the general level of contamination found in a non-operating sampler located at station 251.09 that was exposed to fallout.

Table 5.6 tabulates time of arrival period and time of cessation of fallout within the Bikini Atoll area. Data collected from Project 2.2 and Project 2.5a time-intensity recorder traces are also presented.

TABLE 5.6 - Time of Arrival of Fallout

Station	Sampler	Time of Arrival (min)	Period (min)	Time of Cessation (min)
250.05	Differential Collector	0 + 20	125	0 + 145
250.06	Differential Collector	0 + 25	115	0 + 140
250.22	Differential Collector	0 + 35	60	0 + 95
250.24	Differential Collector	0 + 25	80	0 + 95
251.04	Differential Collector	0 + 30	125	0 + 155
251.05	Differential Collector	0 + 35	90	0 + 125
251.06	Differential Collector	0 + 25	70	0 + 95
251.10	Differential Collector	0 + 40	50	0 + 90
251.03	Time Intensity Recorder	0 + 15	-	-
Dog	(a) Proj. 2.2	<0 + 15	-	-
Oboe	Proj. 2.2	<0 + 15	-	-

(a) See Reference 2 for an account of this project

[redacted]

Analysis of the gamma time-intensity recorder trace located at How gave the best evidence of the rate of arrival of fallout.

Use of the differential fallout collector and the time-intensity recorder for determining the period of fallout was restricted to the lagoon and islands of Bikini Atoll thereby limiting the distance to 15 nautical miles. The average arrival time within the area was 0 + 28 min with cessation averaging 0 + 117 min resulting in an average period of 89 min. These data compare well with that observed at IVY[1] where the period was somewhat less than 2 hr. Residual fallout which was of such quantity that it contributed little to the overall field was found to deposit for a period of several hours after the deposition of the main body of material.

The Bikini Atoll islands along the axis of the fallout pattern experienced fallout over a longer period of time than did those islands located in a crosswise direction.

5.6.2 Shot 2

No evidence was found of primary fallout at early times in the Bikini Lagoon. Secondary fallout of maximum intensity of 40 mr/hr arrived at How Island 37.5 hr after Shot 2, as shown by the gamma time-intensity recorder.

5.6.3 Shot 3

No differential fallout collectors were operative for Shot 3. The gamma time-intensity recorder at How Island indicated a time of arrival of 0 + 38 min. Project 2.2 established an arrival time on Dog Island of approximately 0 + 20 min.[2]

5.6.4 Shot 6

One differential fallout collector located at Alice Island, Eniwetok Atoll, received significant fallout and indicated an arrival time of 0 + 35 min with the period of fallout being 65 min (Fig. C-18).

5.7 RATE OF ARRIVAL OF FALLOUT AND INTEGRATED DOSE

Of the two gamma ionization time-intensity recorders installed on Yoke and How Islands of Bikini Atoll, only the one on How survived and recorded data from Shots 1, 2, and 3. These data give accurate information on rate of arrival of fallout as well as time of arrival.

5.7.1 Rate of Arrival

Table 5.7 presents the time of arrival of fallout and time of peak activity for Shots 1, 2, and 3. The time at which the activity peaks is not the time of cessation of fallout. It is best described as the time at which the rate of decay is greater than the rate of build-up of fallout.

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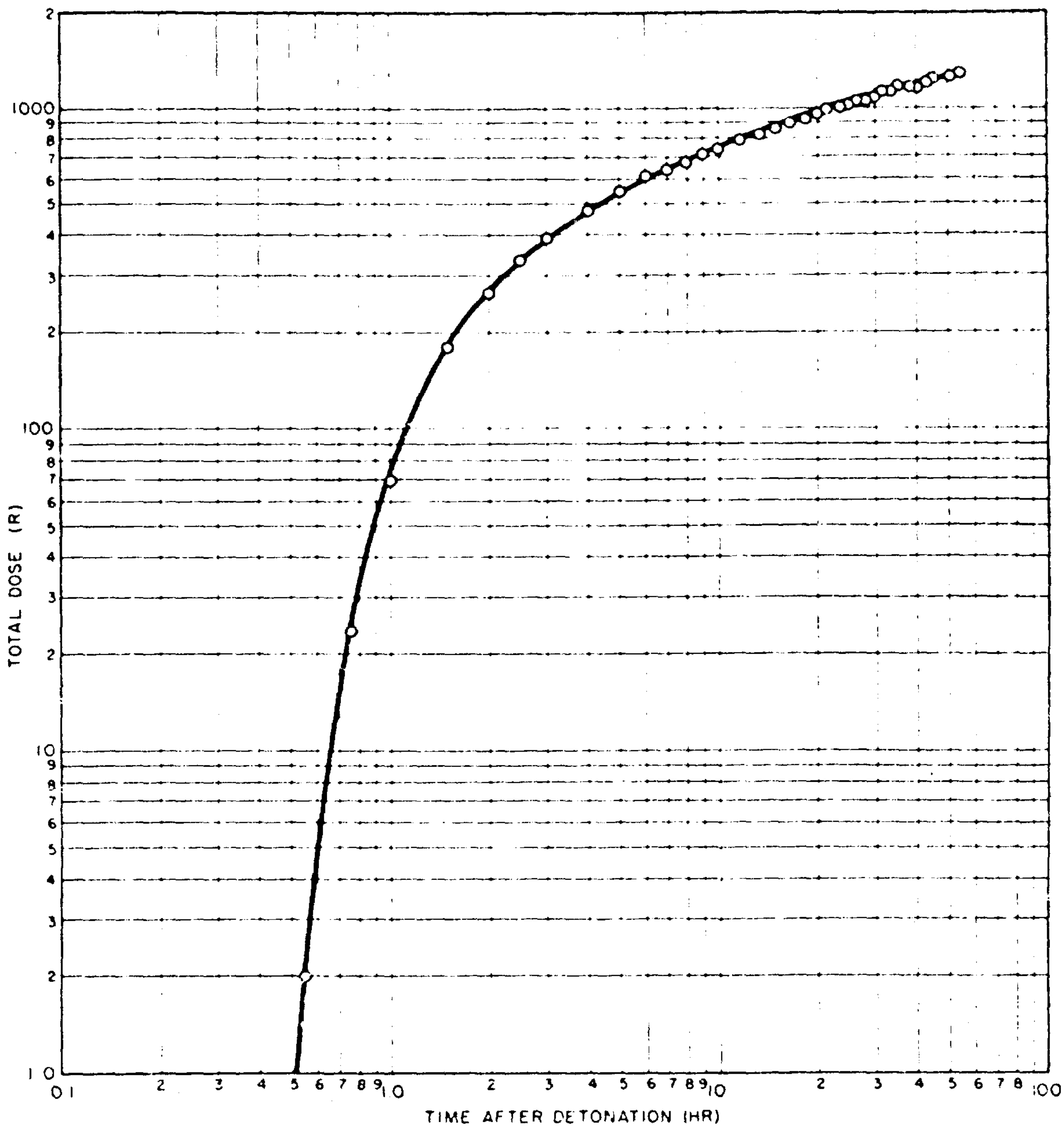

Fig. 5.11 Shot 1, Integrated Gamma Dose, Station 251.03

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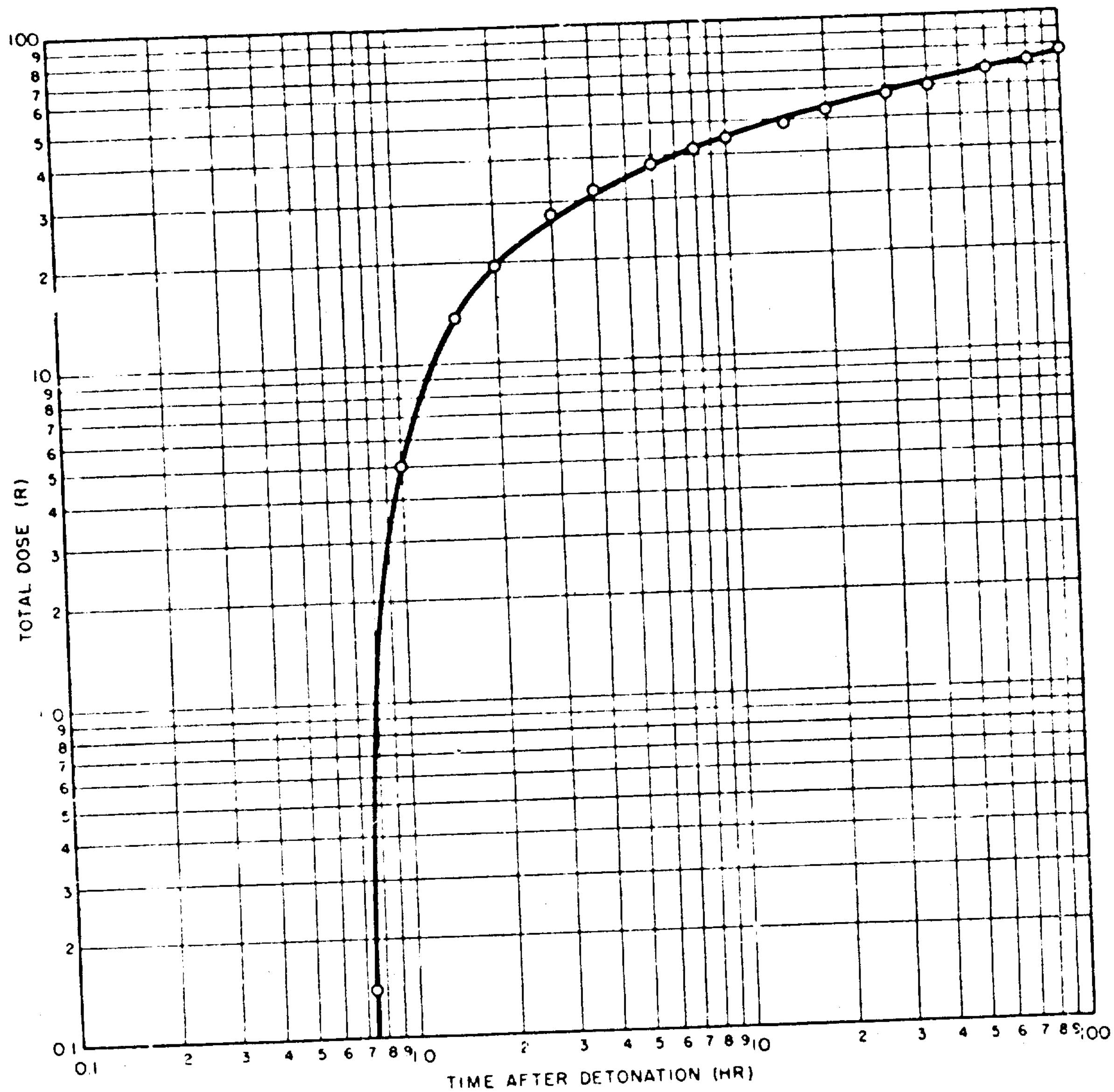

Fig. 5.12 Shot 3, Integrated Gamma Dose, Station 251.03

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TABLE 5.7 - Rate of Arrival of Fallout

Shot	Station	Time of Arrival (min)	Time to Peak Activity (min)	Time Between Fallout Arrival and Peak Activity (min)
1	How Island	0 + 15	0 + 65	50
3	How Island	0 + 38	0 + 66	28
2 (secondary fallout)	How Island	0 + 2250	0 + 3280	1030

5.7.2 Total Dose

Figures 5.11 and 5.12 indicate the integrated gamma dose to a time approximately 100 hr after detonation for Shots 1 and 3. Shot 2 deposited only secondary fallout on How Island and the data are not presented.

[redacted]

CHAPTER 6

PRIMARY FALLOUT PATTERNS

The extent of fallout documentation under the two operational phases of Project 2.5a was different for the various shots. Data were obtained under the land and lagoon phase for Shots 1,3,4, and 6. The lagoon and islands were not contaminated after Shot 2 and no data were taken for Shot 5. Although there was some stem fallout west of the shot point as indicated by the trajectory analysis presented in Section 5.5, the free-floating sea stations for Shot 1 were laid just beyond the westward limit of the gamma field. Consequently the buoys showed that inappreciable amounts of material from Shot 1 fell in the area sampled. For Shot 2, free-floating stations documented fallout to a distance of 50 nautical miles.

A complete analysis of the fallout patterns to a distance of 300 nautical miles is presented for Shot 1. Because of the limited experimental data available for this shot it was not possible to reconstruct the contours on this basis alone. The gamma field data were supplemented by developing an experimental model of the fallout mechanism which defined the axis of symmetry of the pattern. This addition enabled one to construct a complete contour pattern,

Fallout patterns for Shots 5 and 6 were derived from water sampling data and are considered in Project 2.7.[4]

6.1 FALLOUT NEAR GROUND ZERO FOR SHOTS 1,3,4, AND 6

To obtain the infinite field gamma levels within the atolls, three basic collecting devices were placed on the islands and on the rafts within the lagoon as follows:

(a) Total collector - a 7-in. diameter polyethylene funnel fitted to a 1-gal polyethylene bottle.

(b) Gummed paper collector - 1 sq ft of Kum-Kleen acetate-backed paper stapled to a cardboard backing supported in a metal tray.

(c) Project 2.1 film badges placed both vertically and horizontally.

By comparing the laboratory measured levels of gamma activity obtained from samples that were collected on islands with the actual infinite field gamma survey readings, a relationship was developed and

[redacted]

applied to the samples collected at the lagoon stations, thereby permitting estimation of infinite field levels for those locations. Using the total collector as the primary source of data, gamma field contours were thus constructed. Where total collector data were missing, activity levels obtained from the gummed paper collectors were used. All data presented are based on the levels of activity that would have existed had the fallout deposited on an infinite land plane.

The fields as indicated by the film badges were erratic. Because of poor location of the film badges during sampling and unsatisfactory history during and after recovery, these data are not considered in this analysis.

6.1.1 Shot 1

Table 6.1 shows correlation among the data obtained by survey measurements on Bikini Atoll and data obtained from the total collectors and gummed paper collectors located there. All measurements have been converted to r/hr at 1 hr for comparisons.

Figure 6.1 is an isodose rate plot of gamma activity over the atoll. There is indication of a very steep gradient from north to south across the lagoon. This gradient is also indicated in the analysis of Shot 1 particle trajectory data as illustrated in Fig. 6.5.

TABLE 6.1 - Shot 1, Gamma Infinite Field Levels at Bikini Atoll Converted to r/hr at 1 hr as Determined by Various Techniques

Station	Code	Measured by Rad Safe	Measured by Proj. 2.5a	Total Collector Analysis	Gummed Paper Analysis
251.02	Fox	1920	1390	1630	-
251.03	How	510	690	725	528
251.04	Love	270	415	450	-
251.05	Nan	213	208	266	-
251.06	Choe	76	45	51	-
251.07	Uncle	25	17	13	31
251.08	William	21	17	28	26
251.09	Yoke	-	-	-	-
251.10	Zebra	38	21	23	-
250.04	Lagoon	-	-	113	-
250.05	Lagoon	-	-	68	112
250.06	Lagoon	-	-	-	86
250.17	Lagoon	-	-	-	60
250.18	Lagoon	-	-	9.4	-
250.22	Lagoon	-	-	7.5	50
250.24	Lagoon	-	-	20	-

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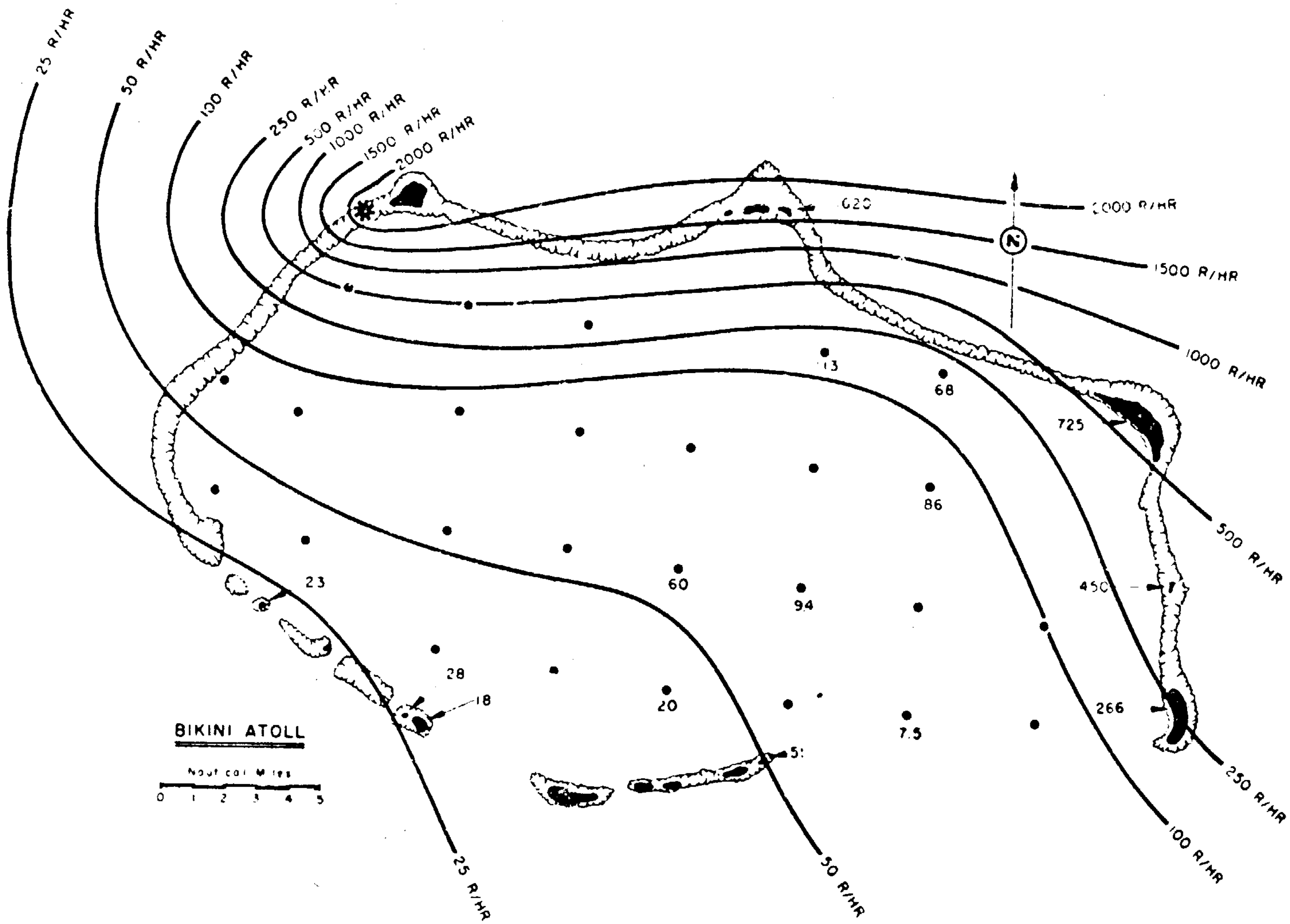

Fig. 6.1 Shot 1, Close-in Gamma Fallout Pattern (r/hr at 1 hr)

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6.1.2 Shot 3

The Shot 3 pattern was well defined because the direction* of fallout crossed the collecting array perfectly. The highest measured level of gamma activity was 360 r/hr at 1 hr at Station 250.17 (see Table 6.2). Figure 6.2 presents the gamma fallout pattern in r/hr at 1 hr.

TABLE 6.2 - Shot 3, Gamma Infinite Field Levels at Bikini Atoll Converted to r/hr at 1 hr as Determined by Various Techniques

Station	Code	Measured by Rad Safe	Measured by Proj. 2.5a	Total Collector Analysis	Gummed Paper Analysis
251.02	Fox	158	-	98	107
251.03	How	16	33	25	20
251.04	Love	3.2	3.3	3.4	-
251.08	William	4.5	-	8.1	-
251.10	Zebra	2.8	1.4	4.2	1.9
250.01	Lagoon	-	-	5.1	-
250.02	Lagoon	-	-	4.2	-
250.05	Lagoon	-	-	107	103
250.06	Lagoon	-	-	62	39
250.07	Lagoon	-	-	64	84
250.08	Lagoon	-	-	33	-
250.09	Lagoon	-	-	4.5	-
250.12	Lagoon	-	-	0.9	-
250.13	Lagoon	-	-	1.5	-
250.14	Lagoon	-	-	2.7	-
250.15	Lagoon	-	-	2.4	-
250.16	Lagoon	-	-	49	65
250.17	Lagoon	-	-	340	360
250.18	Lagoon	-	-	203	201
250.19	Lagoon	-	-	8.5	2.3
250.22	Lagoon	-	-	7	-

6.1.3 Shot 4

The direction* of fallout limited gamma levels of military significance to the northern islands of the atoll. The majority of the lagoon stations were in the fringe area of the fallout pattern. Figure 6.3 and Table 6.3 indicate the extent of the gamma fallout in r/hr at 1 hr for Shot 4.

* Determined from wind data.

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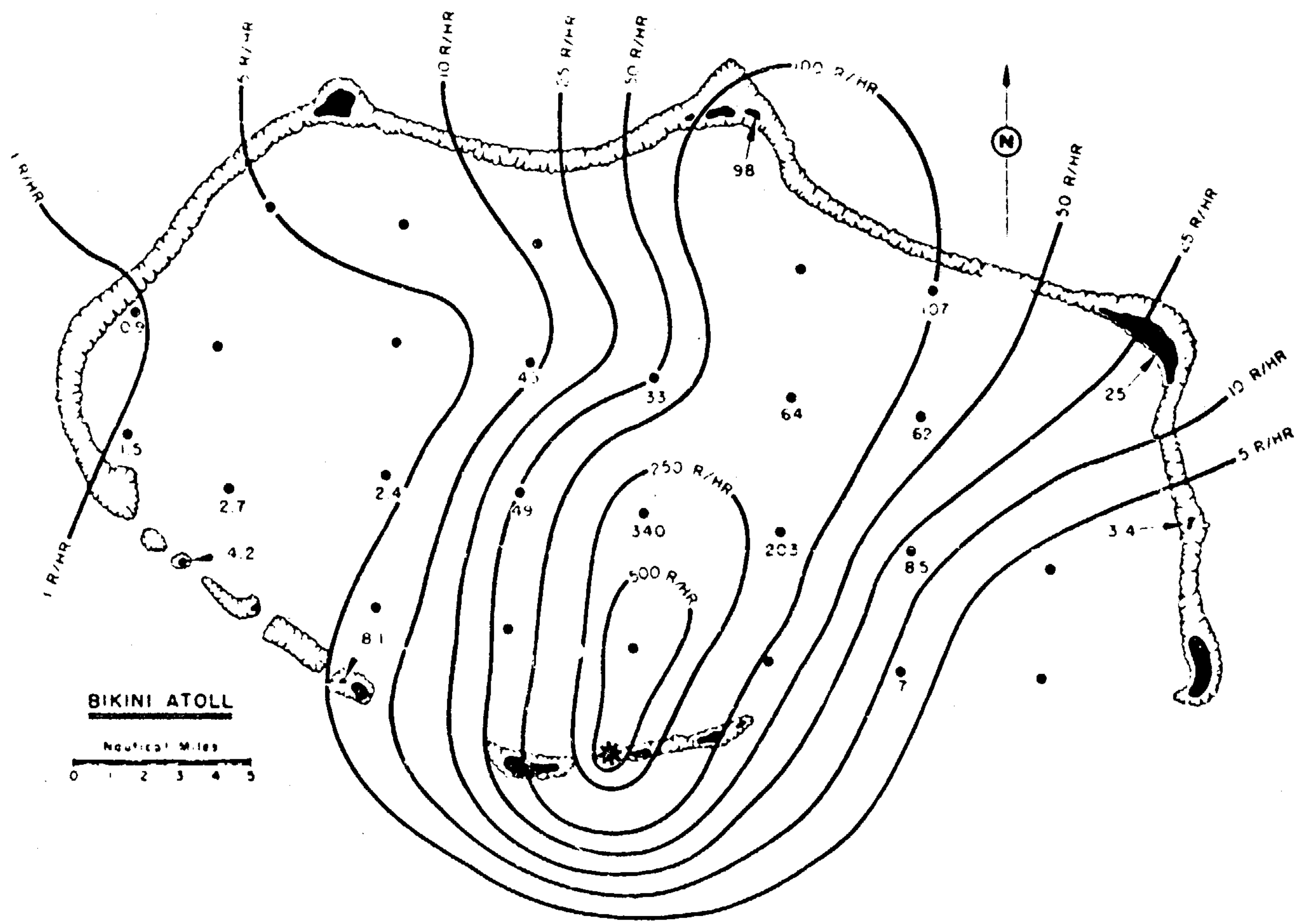

Fig. 6.2 Shot 3, Close-in Gamma Fallout Pattern (r/hr at 1 hr)

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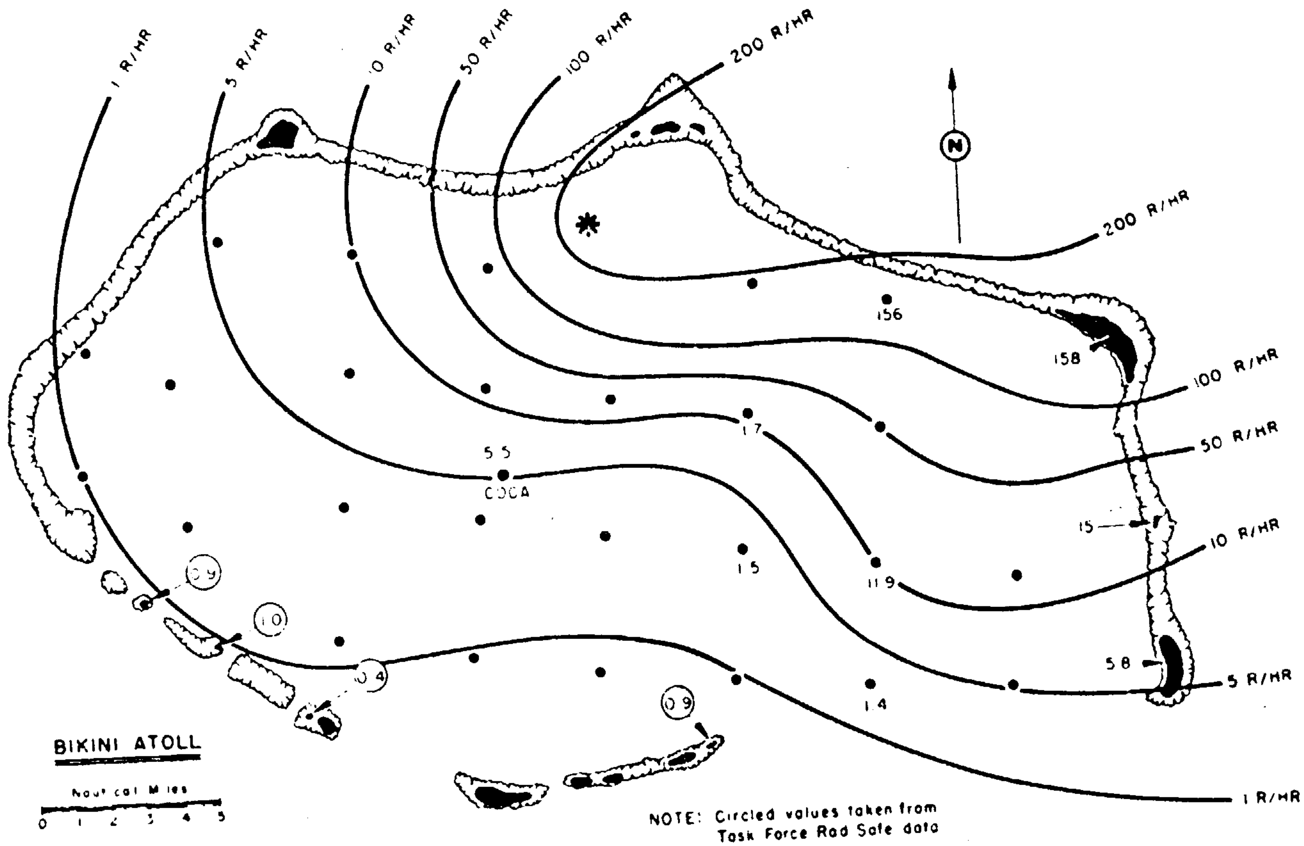

Fig. 6.3 Shot 4, Close-in Gamma Fallout Pattern (r/hr at 1 hr)

[redacted]

TABLE 6.3 - Shot 4, Gamma Infinite Field Levels at Bikini Atoll Converted to r/hr at 1 hr as Determined by Various Techniques

Station	Code	Measured by Rad Safe	Measured by Proj. 2.5a	Total Collector Analysis	Gummed Paper Analysis
251.03	How	128	300	158	-
251.04	Love	15	26	15	-
251.05	Nan	5	4.7	5.8	4.7
251.06	Oboe	0.9	0.8	-	-
251.08	William	-	0.4	-	-
251.09	Yoke	-	1.0	-	-
251.10	Zebra	-	0.9	-	-
250.05	Lagoon	-	-	156	222
250.07	Lagoon	-	-	1.7	0.9
250.18	Lagoon	-	-	1.5	-
250.19	Lagoon	-	-	11.9	1.9
250.22	Lagoon	-	-	1.4	1.3
Coca	Lagoon	-	-	5.5	-

6.1.4 Shot 6

A very complete array of collecting instruments was employed for Shot 6 in the Eniwetok Lagoon and on the atoll islands. Since the fallout went in a northerly direction from shot point very few of the stations received significant fallout. The island of Alice, approximately 3 nautical miles from surface zero, was contaminated to 45 r/hr at 1 hr as indicated in Table 6.4.

The fallout collected was primarily upwind fallout with the gamma field pattern defined in Fig. 6.4. The relatively low levels about surface zero fit well with the overall contours as determined by Project 2.7.

6.2 EXTENDED FALLOUT PATTERN FOR SHOT 1

The contamination of the outlying atolls[15] to the east of Bikini and the measured values of the levels of residual gamma activity following Shot 1 offered an excellent opportunity to evaluate the fallout pattern resulting from a super weapon. A complete analysis of Shot 1 fallout based on available field readings and a comprehensive analysis of the wind structure with respect to its effect on particle trajectories is presented.

6.2.1 Measured Field Values of Residual Gamma Activity

The measured values of residual gamma activity obtained by H. Scoville,[15] were converted to r/hr at 1 hr using the composite gamma ionization decay curve, Fig. 5.3. One hour post detonation is simply a convenient reference; as will be noted in later sections,

[redacted]

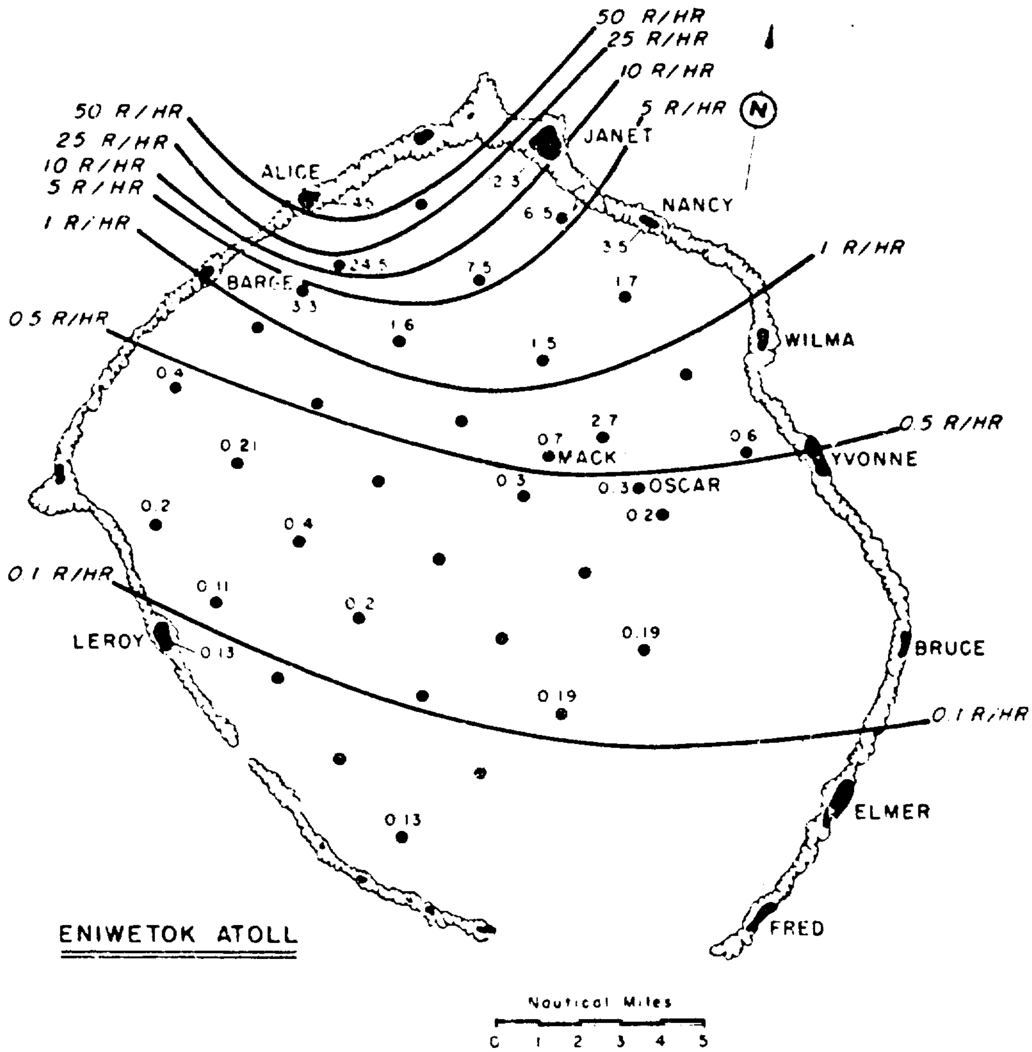

Fig. 6.4 Shot 6, Close-in Gamma Fallout Pattern (r/hr at 1 hr)

[redacted]

TABLE 6.4 - Shot 6, Gamma Infinite Field Levels at Eniwetok Atoll Converted to r/hr at 1 hr as Determined by Various Techniques

Station	Code	Measured by Rad Safe	Measured by Proj. 2.5a	Total Collector Analysis	Gummed Paper Analysis
	Alice	26	42	45	-
	Janet	4.7	5.8	12.3	-
	Leroy	-	-	0.13	-
	Nancy	-	3.3	3.5	-
250.27	Lagoon	-	-	6.5	-
250.28	Lagoon	-	-	1.7	-
250.30	Lagoon	-	-	0.6	-
250.32	Lagoon	-	-	7.5	-
250.33	Lagoon	-	-	1.5	-
250.34	Lagoon	-	-	2.7	-
250.35	Lagoon	-	-	0.2	-
250.36	Lagoon	-	-	24.5	-
250.37	Lagoon	-	-	1.6	-
250.39	Lagoon	-	-	0.3	-
250.41	Lagoon	-	-	0.19	-
250.47	Lagoon	-	-	0.19	-
250.48	Lagoon	-	-	0.4	-
250.49	Lagoon	-	-	0.21	-
250.50	Lagoon	-	-	0.4	-
250.51	Lagoon	-	-	0.2	-
250.54	Lagoon	-	-	0.2	-
250.55	Lagoon	-	-	0.11	-
250.58	Lagoon	-	-	0.13	-
MAC-1	Lagoon	-	-	0.7	-
Barge	Lagoon	-	-	8.3	-
Oscar	Lagoon	-	-	0.3	-

fallout first arrived at the outlying atolls several hours after detonation. These data (Table 6.5), along with the measurements made within the Bikini Atoll as shown in Fig. 6.1, represent the available gamma field measurements used in this analysis.

6.2.2 Determination of Experimental Model - Shot 1

Although significant gamma field data were obtained, they fell far short of completely defining the fallout pattern. However, with the added knowledge of the axis of symmetry of the fallout pattern,

[redacted]

TABLE 6.5 - Shot 1 Residual Gamma Activity on Outer Islands

Location	Gamma Activity r/hr at 1 hr
Ailinginae	
Enibuk	92.5
Sifo	77
Lokonikaiaru	108
Rongelap	
Naen	2420
Arrik	1950
Lomuilal	1950
Gejen	1950
Lukuen	1160
Eriirippu	1480
Kabelle	1050
Anidjet	737
Enialo	264
Eosch	342
Rongelap	197
Arqar	132
Eniran	316
Rongerik	
Bok	770
Latobae	385
Mortlock	347
Rongerik	308
Eniwetak	216
Utirik	
Aon	26.6
Utirik	20
Bikar	
Bikar	93.3

gamma field contours were constructed. This information was obtained by completely analyzing the wind structure existing at and after shot time with respect to its effect on fallout particles originating in the stem and cloud. To establish a pattern on this basis it was necessary to make the following assumptions:

(a) The relative contribution of particles less than 25 μ in diameter to the residual gamma field defining the area of primary fallout was negligible.

(b) The particle size distribution is the same at all elevations and homogeneous throughout the visible dimensions of the cloud and stem. This assumption was arbitrarily chosen as the best

[redacted]

approximation to the actual case. Consideration of the extreme vertical velocities and violent turbulence existing within the cloud before stabilization makes it appear unlikely that any major fractionation of particle size would occur within the cloud and stem at early times. However, any error introduced in the resultant axis of symmetry as a consequence of this assumption would be minor because of the particular wind situation throughout Shot 1 fallout.

(c) A vertical line from ground zero to the maximum elevation of the cloud represents the axis of symmetry of the stem and cloud.

(d) The physical dimensions of the cloud and stem can be satisfactorily represented by assuming they define cylinders about the vertical axis of symmetry of the detonation.

The above assumptions defined a simplified model of the Shot 1 cloud from which, with information obtained experimentally and the complete wind data, the particle trajectories were calculated and their points of intersection with the surface of the earth determined as well as were particle transit times.

6.2.3 Experimental Data Applied to Model Evaluation

The following experimental data were used to complete this analysis:

(a) From the particle size analysis of the Bikini Atoll and outer island atoll fallout, (see Section 5.2) it was determined that the particulate were almost entirely irregular in shape.

(b) The average apparent density of these particles was determined to be 2.36 g/cu cm as discussed in Section 5.4.

(c) The size distribution of the fallout particulate ranged between 2000 and 25 μ in diameter.

(d) The cloud dimensions both vertical and horizontal were obtained by cloud photography.[5]

(e) Meteorological data of the variation with height of both the wind direction and speed, and the air temperature were obtained from the Task Force Weather Central.

6.2.4 Determination of Particle Trajectories

From consideration of the above assumptions and application of the measured particle data the terminal velocities of the fallout particles were calculated from aerodynamic falling equations. (See Appendix E.) The atmosphere was then divided into 5000-ft increments from the surface to 100,000 ft and the average wind speed and direction within these increments was determined. With knowledge of the rate of fall of the various size particles and the wind vectors acting on these particles their trajectories were computed. Particles of 2000, 1500, 1000, 750, 500, 375, 250, 200, 150, 100, 75, 50, and 25 μ in diameter were placed at 5000-ft increments in the cloud model. Each particle size at each starting elevation was then followed through the atmosphere. Comprehensive use of the available wind data was made in computing the particle trajectories. Effects of both space and time variations on the winds were fully considered. The upper air data from Eniwetok, Bikini,

[redacted]

and Rongerik Atolls from 0 hr through 0 + 6 hr were used. Since the primary fallout was deposited over the area between Bikini Atoll and Rongelap Atoll within the first 8 hr, no extrapolation of the wind data was necessary for these particles. However no wind data after H + 6 hr were available for the area beyond the Rongerik Atoll and a time extrapolation had to be used in determining the winds that fixed the particle trajectories there. In plotting the trajectories it became obvious that particles above 1000 μ in diameter would fall very near ground zero. Consequently, no calculations were made on the 1000, 1500, and 2000 μ particles.

Figure 6.5 shows the terminal points of the 231 trajectories evaluated. The primary effect of the larger particles is evident at distances close to ground zero.

6.2.5 Consideration of Cloud Dimensions

The maximum lateral width of the fallout area was determined by expanding each particle's arrival point to the diameter of the stem or cloud from which the particle originated. From the cloud photography data the stem diameter was found to be 6.6 miles, the stem height 60,000 ft, the cloud diameter 66 miles and the cloud height 100,000 ft at 0 + 10 min. These dimensions were chosen although the cloud continued to expand laterally after 0 + 10 min. For simplicity it was assumed in this model that the cloud and stem were cylinders having these dimensions. This evaluation assumes no cloud diffusion with time, but fully considers shear.

6.2.6 Determination of Axis of Symmetry of the Fallout Pattern

From the swath of points (Fig. 6.5) the direction of fallout was determined. Since the particle arrival points had a narrow spread it seemed reasonable to construct an axis about which the fallout was symmetrical. Such a symmetrical fallout pattern results only if the upper winds have the necessary configuration for so restricting the particle trajectories. The time of arrival of the particles was also calculated, Table 6.6. Some of the calculated trajectories of the smaller particles starting at high elevations did not reach the surface until many hours after the main body of material had deposited. These arrival points indicative of secondary fallout were not considered in the determination of the axis of symmetry.

6.2.7 Construction of the Fallout Pattern

Using the established axis of symmetry of fallout in conjunction with the measured levels of gamma activity on the available atolls a complete fallout pattern (r/hr at 1 hr) was constructed as presented in Fig. 6.6. This pattern shows the levels of fallout that would exist on an infinite land plane should the basic assumptions used in the definition of the experimental model hold. It is important to note that this pattern was constructed solely on consideration of the gamma field measurements and the axis of symmetry: however, there is other supporting

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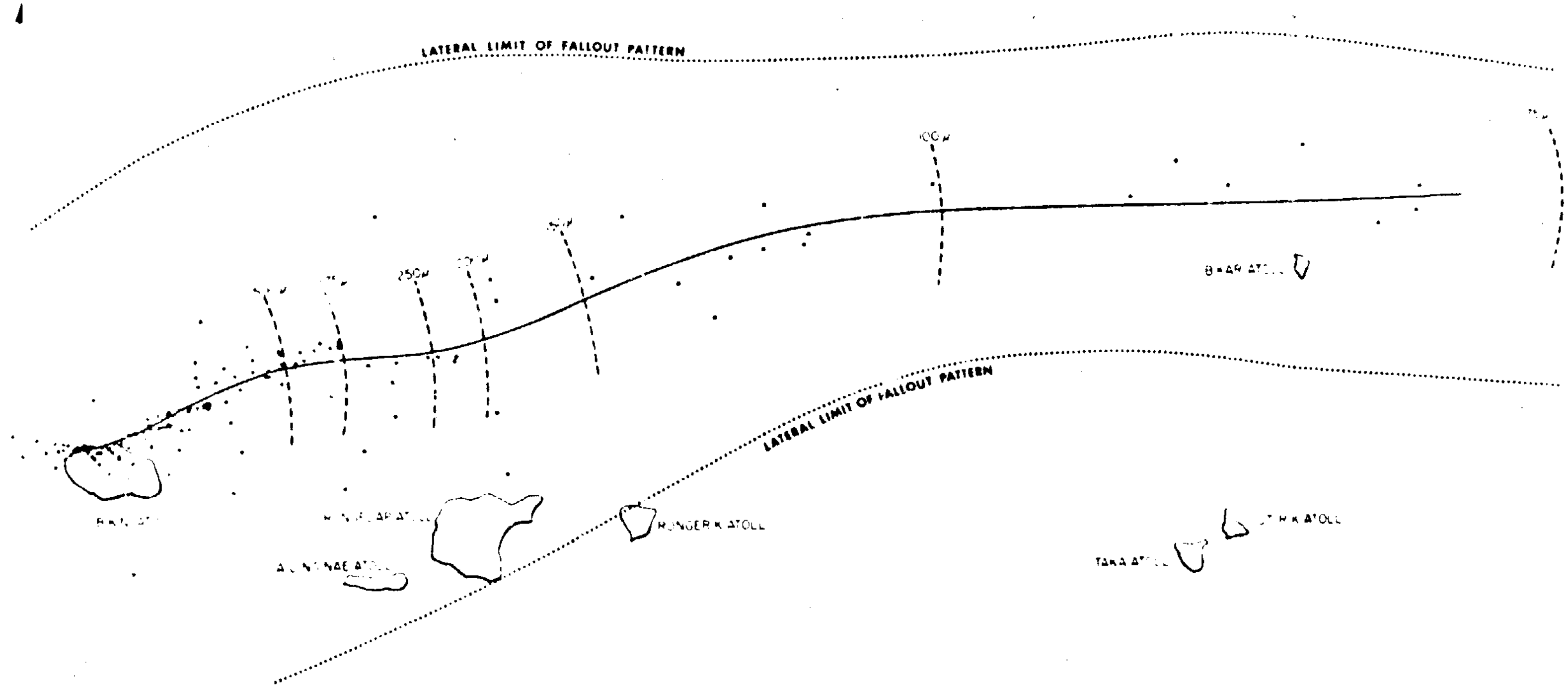

Fig. 6.5 Shot 1, Calculated Direction of Fallout From Analysis of Particle Trajectories (dashed lines indicate limiting distance of stated particle sizes)

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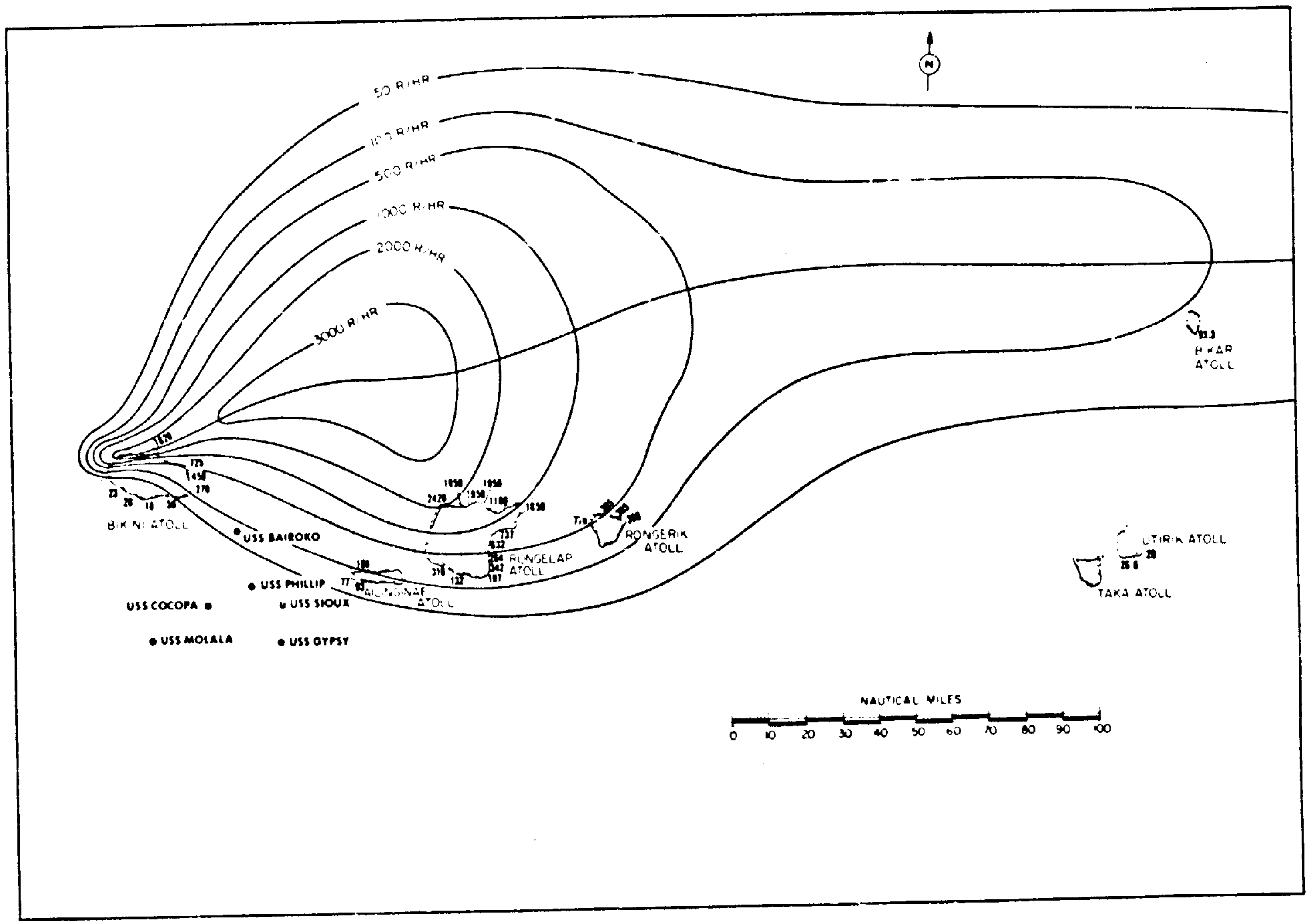

Fig. 6.6 Shot 1, Reconstructed Complete Fallout Pattern (r/hr at 1 hr)

[redacted]

evidence available from the analysis of the particle trajectories. The maximum lateral dimension of the fallout pattern as indicated in Fig. 6.5 agrees well with the constructed pattern. The density of arrival points should be related to the levels of activity; this offers further reason to construct the area of peak activity to the north of Rongelap Atoll.

6.2.8 Evaluation of the Shot 1 Fallout Pattern

To determine the time of arrival of fallout, Fig. 6.13 was constructed based on the times as determined from the particle trajectory analysis. Included in the analysis was the effect of the cloud dimensions. Comparison of this calculated time of arrival with the reported[4] time of arrival on the outer islands indicates the validity of the calculated rates of fall of the particles. Table 6.6 presents this comparison.

TABLE 6.6 - Shot 1, Comparison of Calculated and Observed Times of Arrival of Fallout

Distance (n miles)	Calculated Time of Arrival (hr)	Observed Time[(a)] of Arrival (hr)
14	1.1	1
50	2.1	-
87	4.7	7
100	5.9	-
126	7.8	8
150	8.9	-
200	11.1	-
250	13.2	-
302	15.4	18

(a) Taken from Reference 1.

The reliability of the observed times of arrival on the atolls inhabited by natives are open to some question because of poor documentation. This appears to be especially true of the 7 hr arrival time at the atoll of Rongelap. The weather island of Rongerik at 126 nautical miles reported observed arrival times that compare well with the calculated values.

An attempt to determine the average period of fallout was made by evaluating the trajectory data as shown in Fig. 6.13. This was done by obtaining an average time of cessation of fallout. The rate of arrival of fallout at How Island caused the majority of the activity to be deposited early in the total period of fallout (see Section 5.7). On the basis of this observation the curve indicating the time of cessation of fallout (Fig. 6.13) was weighted showing the period of fallout ending before all particulate had arrived. It is at this time that the level of gamma activity peaks. Continuing fallout after this time is of

[redacted]

such small magnitude that decay is greater than build-up.

Another check on the validity of the analysis using the experimental model was a comparison of the particle size distribution as measured from samples collected on the atolls and the size distribution that would be expected from consideration of the trajectories of the particles. Table 6.7 tabulates the measured particle size distribution found in samples from the atolls as taken from the data presented in Chapter 5.

TABLE 6.7 - Shot 1, Measured Particle Size

Station	Smallest Particle (μ)	Largest Particle (μ)	Geometric Mean (μ)
Bikini	<25	>1000	112
Ailinginae	16	172	60
Rongelap Village	10	126	
Rongelap North End	16	394	70
Rongelap, Kabelle	16	518	
Utirik	6	134	45

The calculated trajectories showed particles from 2000 to 100 μ arrived as primary fallout within the Bikini Lagoon. This fact agrees very well with the measured size distribution shown in Table 6.7. Consideration of the cloud diameter and stem diameter, in the experimental model, on the arrival points of the particle trajectories indicates particles from 150 to 75 μ diameter would arrive at the north end of Rongelap with the limit of the 250 μ particles falling approximately 10 nautical miles north of Rongelap Atoll. The steep gradient of particle size distribution in a north-south line is also clearly indicated from the model study which agrees well with the size distribution found at Ailinginae some 15 nautical miles south of north Rongelap. Also the calculated size limits the particles arriving at a distance of 300 nautical miles to a maximum diameter of 75 μ as compared to a measured geometric mean size of 45 μ.

The only discrepancy of any magnitude between observed data and those calculated from the experimental model is that no fallout arrived at Utirik based on the model analysis. It must be realized that at this distance the model analysis is weakest because the wind data used were extrapolated as being constant from 0 + 6 hr to 0 + 20 hr, the latter being the time of arrival of fallout at a distance of approximately 300 nautical miles. This extrapolation was necessary because no wind data for periods beyond 0 + 6 hr was available at the time of this analysis.

Even better correlation of measured to calculated particle size would be obtained if a larger cloud diameter were used in the experimental model. For this analysis the value used of 66 nautical miles was conservatively chosen; Project 9.1 cloud dimension data indicate

[redacted]

the cloud continued to grow laterally to a diameter larger than 66 nautical miles at the time of their last reported measurement, 0 + 10 min.

The fallout contours from this analysis indicate higher levels of activity 60 nautical miles distant than those existing within 10 miles of the detonation point. The pattern is much wider than would be obtained by scaling the surface shot from Operation JANGLE. For matters of comparison surface JANGLE was scaled to 15 MT by the cube root scaling relationship. This pattern is shown in Fig. 6.7 on the same map scale as the Shot 1 pattern presented in Fig. 6.6. The resulting comparison is interesting, primarily from the point of view of the extreme variation in the configuration of the two patterns. Justification of fallout contours of higher yield devices having little or no relationship to the scaled JANGLE surface detonation contours is evidenced in an analysis of cloud dimensions with respect to yield.[11] The reference indicates that a change of cloud shape takes place with increasing yields becoming gradually flattened for higher yields. This flattening effect would indicate a resulting wider pattern than one would obtain by simply scaling the JANGLE surface data.

This configuration is also evidenced in the analysis of the Shots 5 and 6 fallout patterns.[4]

6.2.9 Material Balance for Shot 1

Two material balances were made on the resulting Shot 1 fallout pattern. The bases for these balances were theoretical in one case and experimental in the other. (See Appendix F.)

The theoretical calculations resulted in 57 per cent of the measured yield of the Shot 1 device being accounted for within the 100 r/hr at 1 hr contour. Also, the theoretically calculated fraction of the device deposited at Station 251.03 was found to be 7.0×10^{-16}/sq cm.

The fallout in a total collector located at Station 251.03 was analyzed radiochemically and the results showed 3.7×10^{-16} of the device was deposited per square centimeter at this location. Extrapolating this ratio over the fallout pattern after taking into consideration the varying levels of activity resulted in approximately 30 per cent of the device being accounted for. This value is questionable because of the fragmentary data upon which it is based. However, the two results indicate that the fallout pattern as constructed for Shot 1 is within reason.

Table 6.8 indicates the average gamma activity in r/hr at 1 hr with respect to the areas over which these fields existed.

TABLE 6.8 - Areas of Average Gamma Activity

Area (sq. miles statute)	Residual Average Gamma Activity (r/hr at 1 hr)
2,040	3,000
2,880	2,500
3,360	1,500
6,030	750
12,900	300

[redacted]

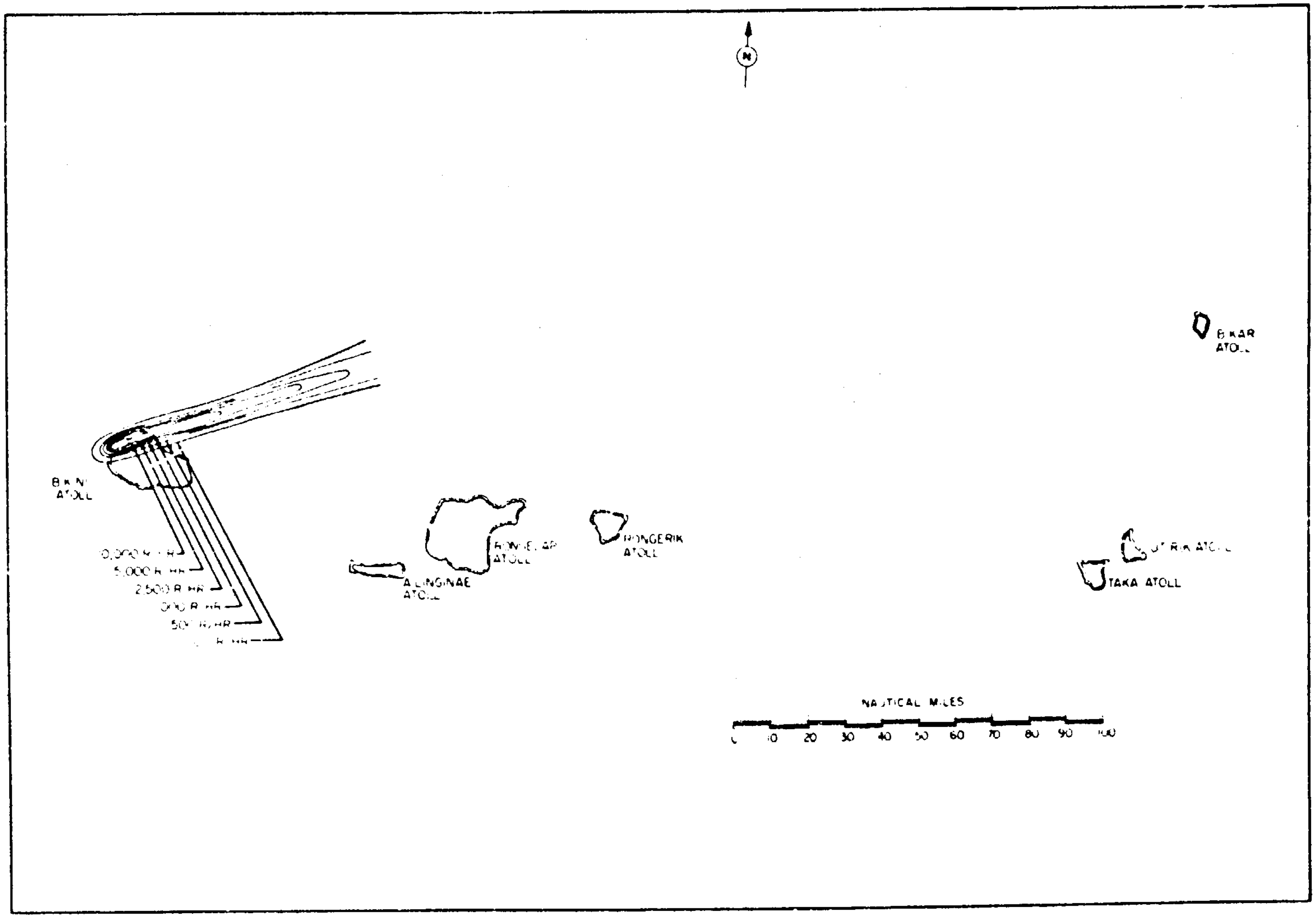

Fig. 6.7 JANGLE Surface Shot Scaled to 15 MT (r/hr at 1 hr)

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6.2.10 Growth of Shot 1 Fallout Pattern with Time

It must be realized that the reconstructed fallout pattern described in Fig. 6.6 indicates for convenience the levels of activity t that would exist should all of the fallout particulate be down at 0 + 1 hr. Of course, this is not the case, for the primary pattern out to approximately 280 nautical miles was not static until some 20 hr after shot time. Figures 6.8 through 6.12 show the growth of the pattern with time. The gamma field levels are those that would exist at these times over a land area. In construction of these patterns consideration of both decay and time of arrival as indicated by Fig. 6.13 were taken into account.

6.3 EXTENDED FALLOUT PATTERN FOR SHOT 2

Bikini Atoll was not heavily contaminated after Shot 2 was detonnated due to the primary fallout falling to the north of the shot point. Eleven of the samples from the free-floating sea stations recovered after Shot 2 were evaluated and it was found that the main swath of fallout crossed over the station array. Of the 11 stations recovered seven were in the fallout area as indicated by Table 6.9. The total collector data were reduced and analyzed by Project 2.6a.[18]

TABLE 6.9 – Shot 2, Gamma Infinite Field Levels Converted to r/hr at 1 hr as Determined by Various Techniques

Station	Bearing from Ground Zero (degrees true)	Distance from Ground Zero (n miles)	Gummed Paper Collector Analysis (r/hr)	Total Collector Analysis(a) (r/hr)
A_4	352	43	120	120
O_4	247	34	0.24	2.0
P_4	271	34	1.0	0.1
Q_4	295	34	33	110
R_4	308	36	435	480
T_4	337	43	220	90
A_5	347	52	147	90
D_5	054	53	0	-
E_5	075	53	0	-
F_5	095	53	0	-
G_5	115	53	0	-

(a) As evaluated by Project 2.6a.

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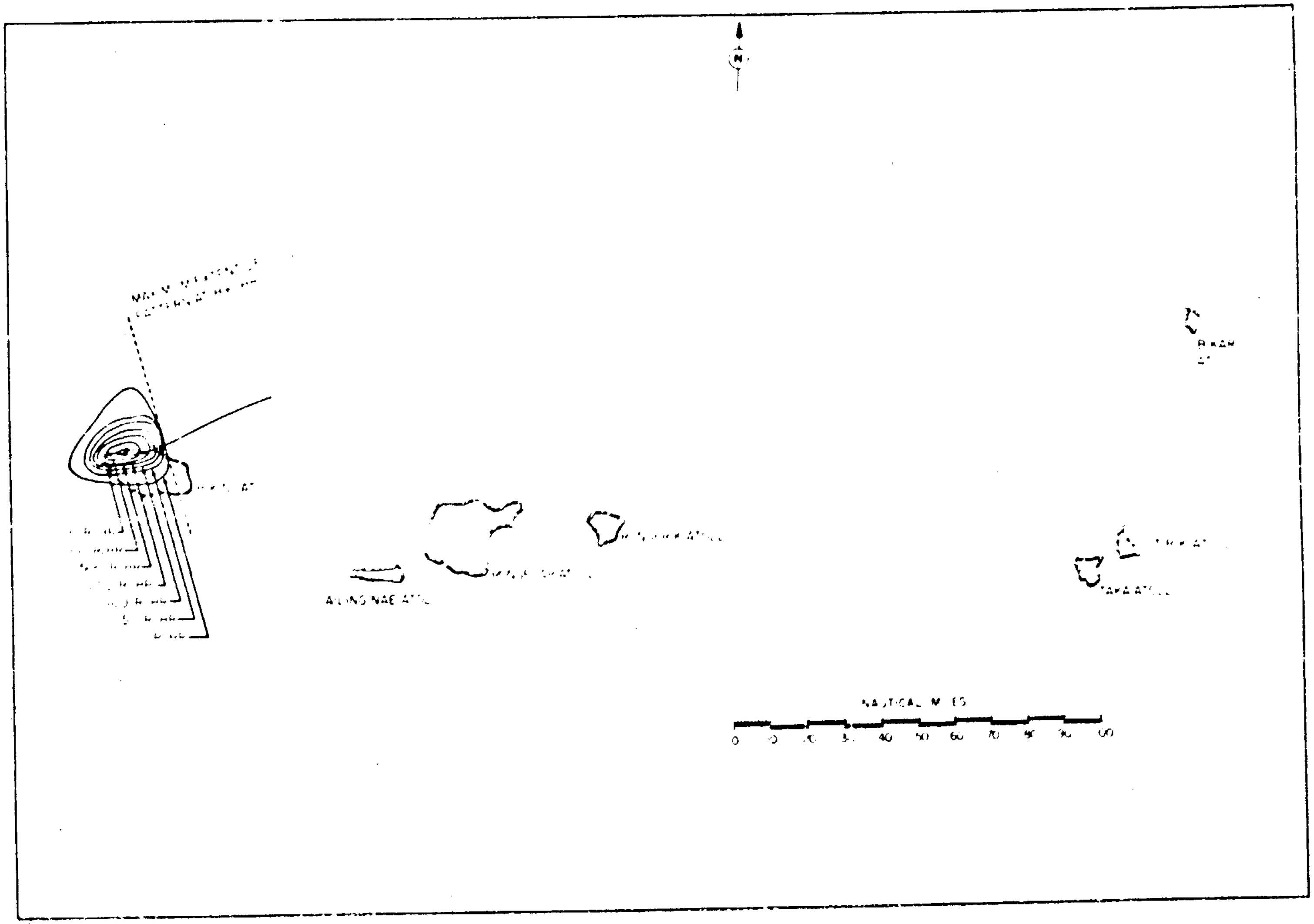

Fig. 6.8 Shot 1, Reconstructed Fallout Pattern at 1 hr

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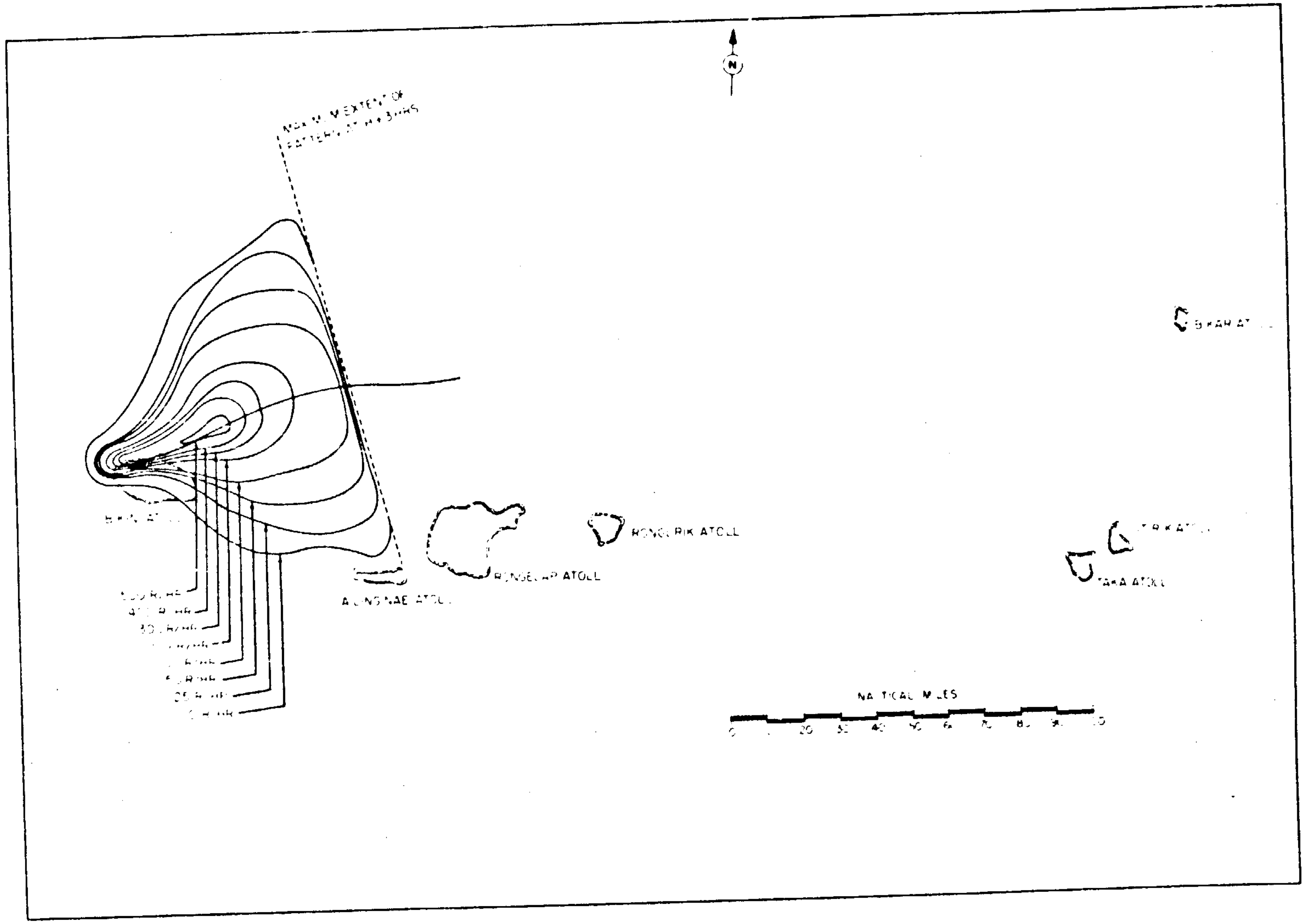

Fig. 6.9 Shot 1, Reconstructed Fallout Pattern at 3 hr

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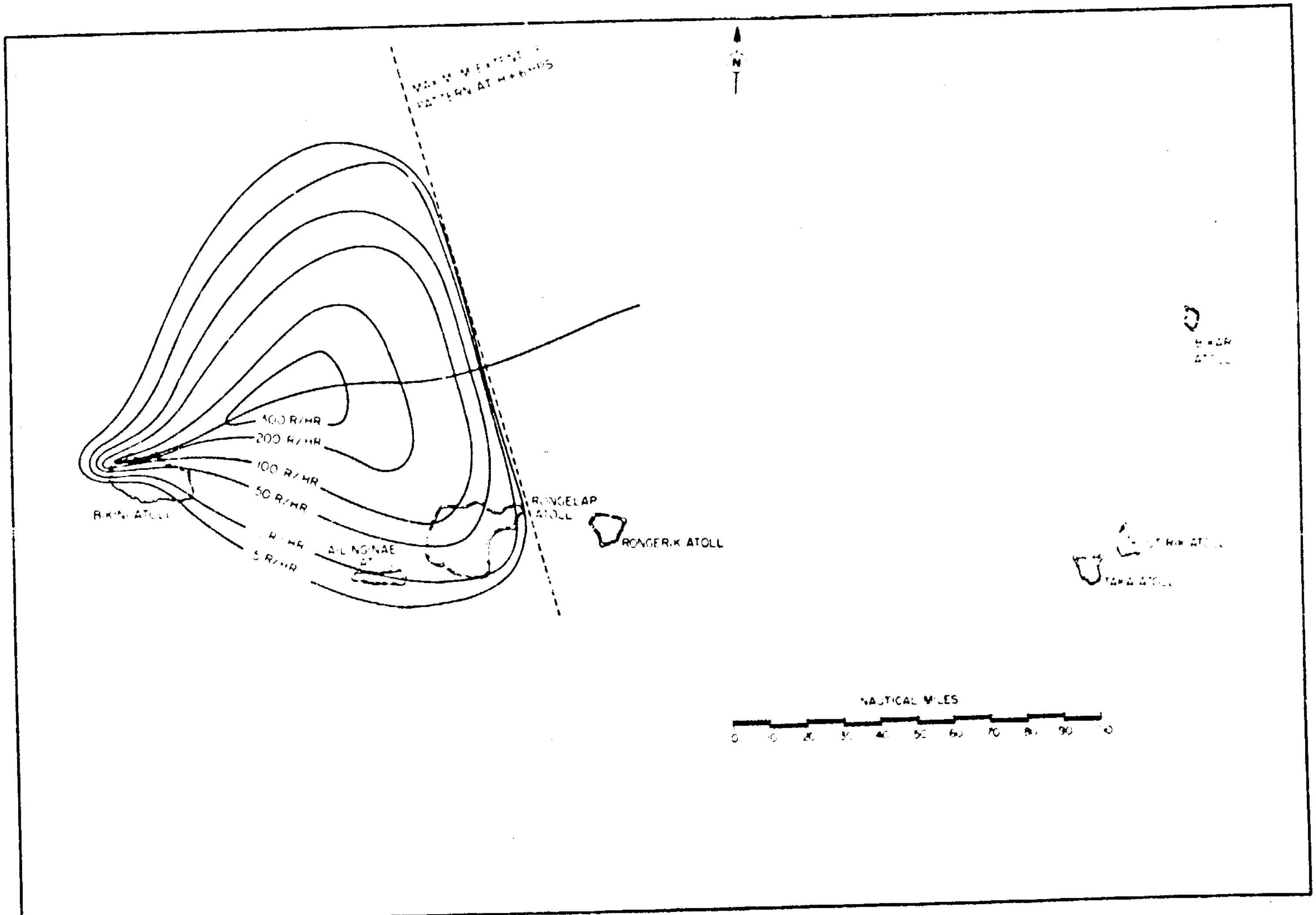

Fig. 6.10 Shot 1, Reconstructed Fallout Pattern at 6 hr

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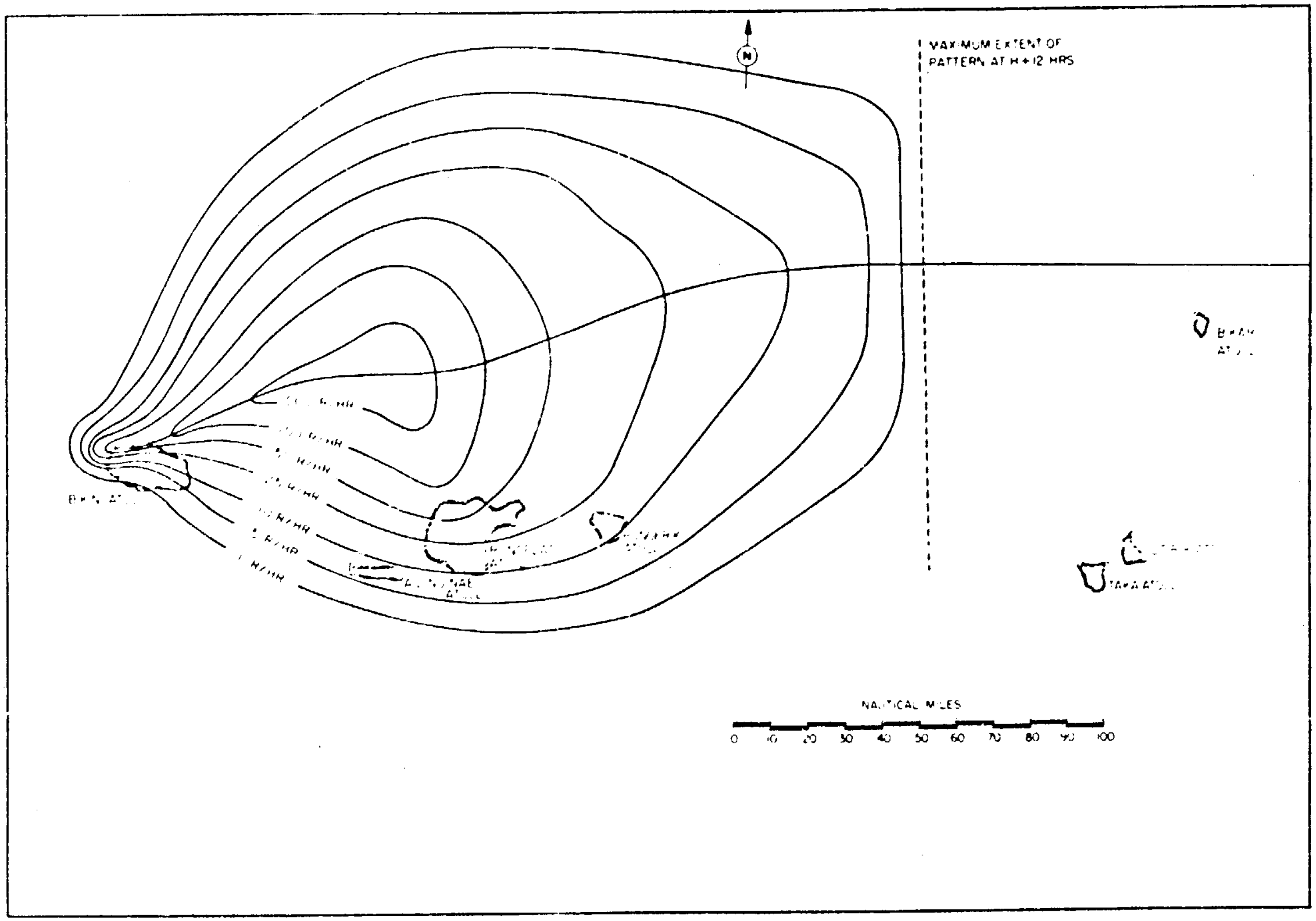

Fig. 6.11 Shot 1, Reconstructed Fallout Pattern at 12 hr

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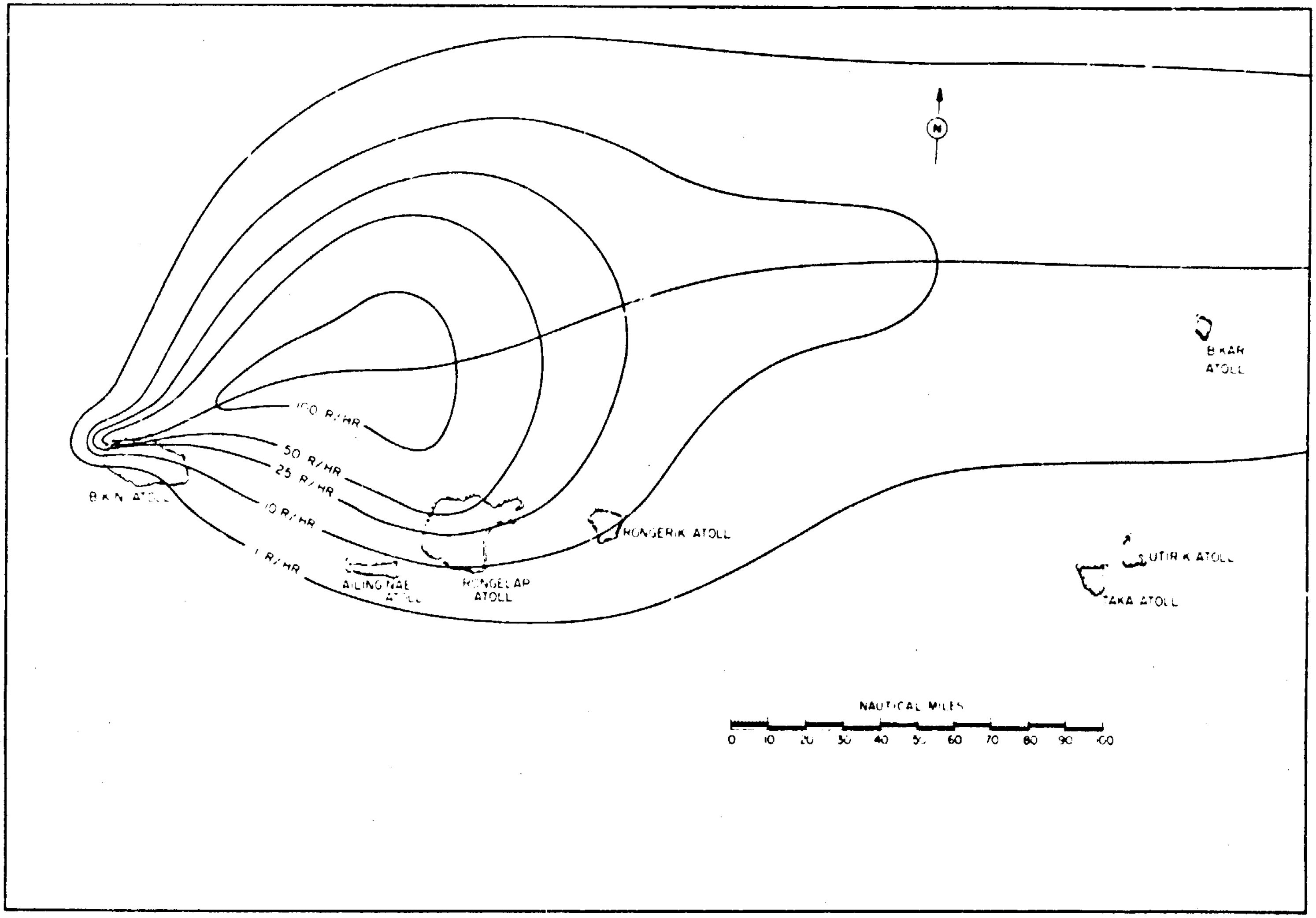

Fig. 6.12 Shot 1, Reconstructed Fallout Pattern at 13 hr

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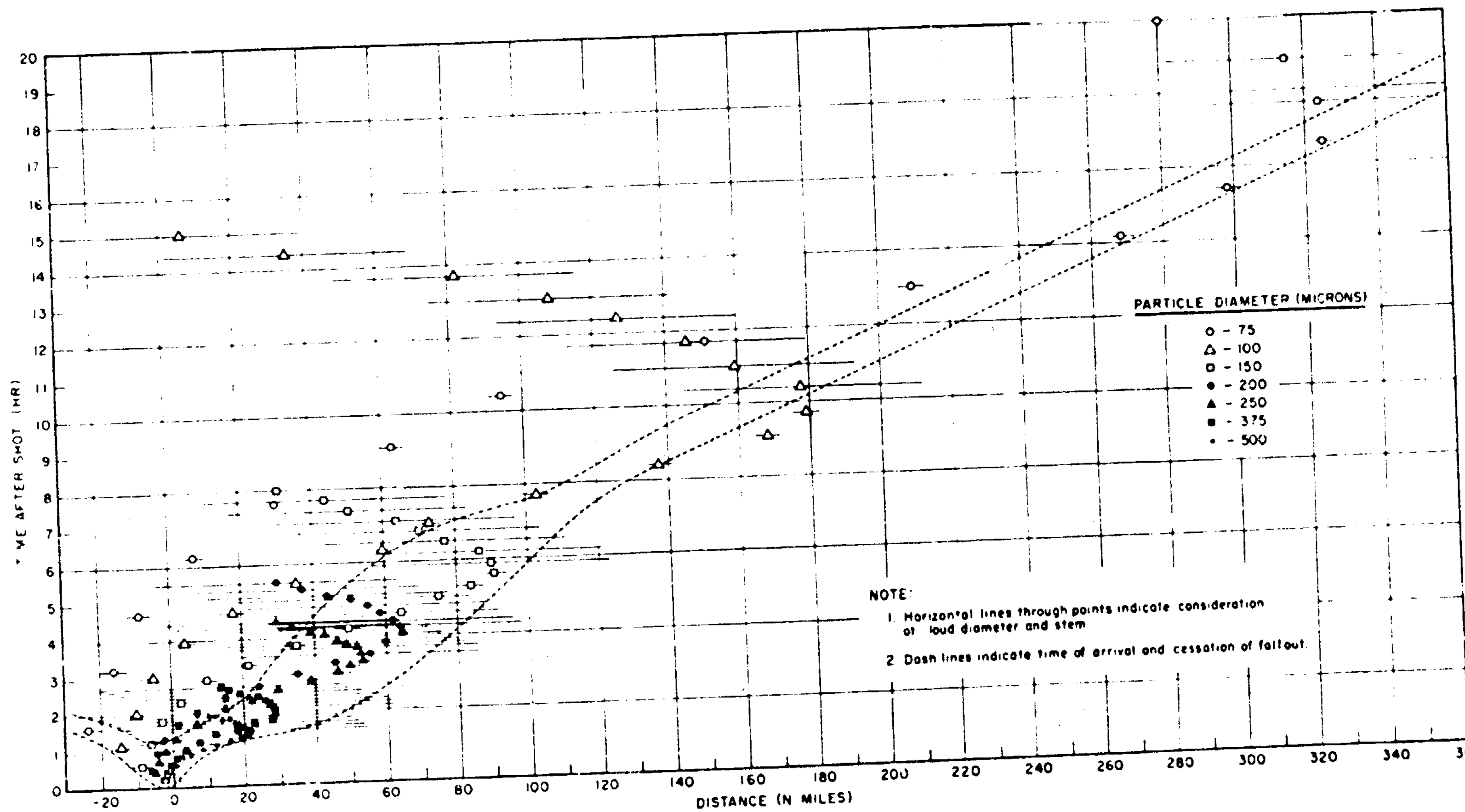

Fig. 6.13 Shot 1, Calculated Time of Arrival and Cessation of Fallout Based on Calculated Particle Trajectories

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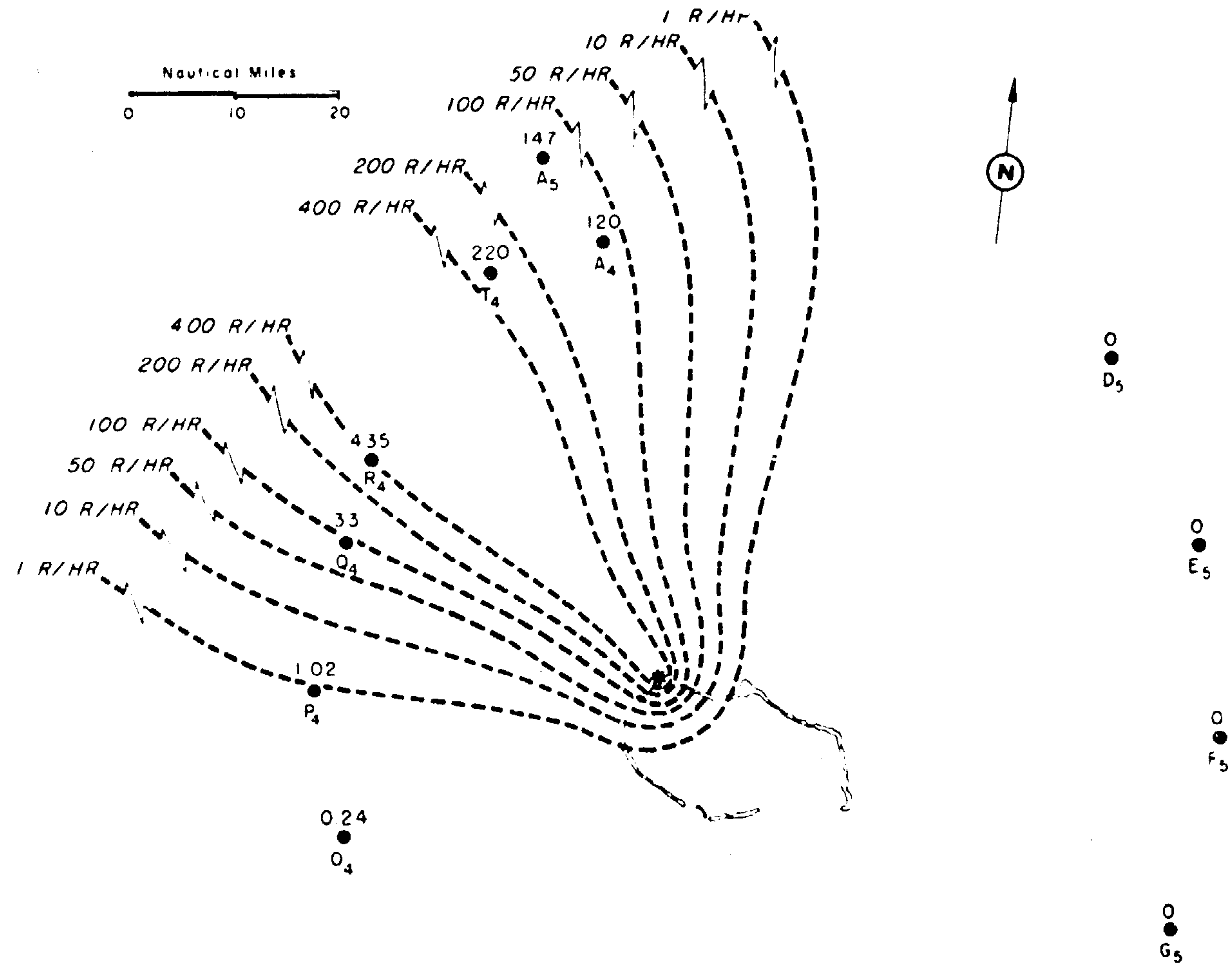

Fig. 6.14 Shot 2, Fallout Pattern (r/hr at 1 hr)

[redacted]

The fallout contours constructed from the gummed paper data are presented in Fig. 6.14. Since the data were fragmentary, limited reliability should be placed on the configuration of the contours. No analysis of the pattern based on particle trajectory data has been attempted.

CHAPTER 7

SUMMARY

7.1 GENERAL OBSERVATIONS

The study of thermonuclear explosions at CASTLE has shown the fallout problem to be of considerably greater magnitude than predicted. This demonstration of the radiological capabilities of superweapons makes it imperative that scaling relationships for fallout be derived which will apply over the entire range of possible weapon yields. A common basis of development is required if predictions are to be valid for the now undocumented medium yield range (high yield fission--low yield thermonuclear). Such a basis may be found in the changes in cloud geometry which are known to occur with changes in yield.

The increased coverage by fallout appears to be due to the flattening of the source cloud at high yields in contrast to the more nearly spherical cloud shape of the nuclear model used for the predictions. The following general observations may be drawn concerning fallout from the more diffuse source:

(a) The extent of land gamma radiation fields of military significance is increased beyond that directly attributable to the increase in yield over the nuclear range.

(b) This increase in the area of lethality is the result of a more even distribution of fallout over a larger area. Stating it another way, reduction of the extra-lethal or over-kill factor extends the lethal range for fallout.

(c) The increased efficiency with which superweapons disperse radioactive materials is to some extent counter-acted by the delay in arrival of fallout from the high source cloud and the rapid rate of decay which occurs in the interim.

7.2 PLANS FOR FURTHER WORK

Further study of the interaction of these three factors and comparisons with model data are expected to reveal the part cloud geometry plays in the distribution of fallout. Correlation of data from all CASTLE sources, including the results of water sampling under Project 2.7, will be made using the USNRDL experimental model. Idealized gamma

[redacted]

isodose and isodose rate contour plots will be developed for the two types of explosions, surface-land and surface-water, taking into account the time of fallout arrival. Comparisons with other models and with nuclear data will be carried out and the cloud geometry factor examined. The contribution which these upper yield limit data make to the development of scaling relationships can then be fully evaluated.

Improvements of and generalizations on the experimental model are expected to accompany the foregoing analyses. Use of the method as a tool for forecasting primary fallout appears promising and will be explored.

Additional development and evaluation of data on gamma field decay will be carried out. Idealization of the decay curve from 5 to 500 hr post detonation is expected to produce a simplified approximation suitable for military planning and field use. This approximation may reduce to two straight line functions on a logarithmic plot, one covering the period from 5 to 50 hr, and the other, 50 to 500 hr. Later decay is assumed to follow the normal fission product function.

7.3 SPECIFIC CONCLUSIONS

The following conclusions present evaluation of data on primary fallout at CASTLE:

(a) Gamma fields from fallout decayed at rates differing from the $t^{-1.2}$ approximation common to fission weapons. The extent of this difference is militarily important over certain time periods.

(b) Fallout from the surface land detonations was in the form of irregular solid particulates. The geometric mean particle diameter decreased with distance from the shot points; for Shot 1 the geometric mean varied from 112 μ at Bikini Atoll to 45 μ at Utirik Atoll.

(c) Of the solid particulates studied, approximately 25 per cent were inactive with their mean particle size smaller than the active.

(d) The average density of the solid particles from Shot 1 was 2.36 g/cu cm.

(e) Little data were obtained on the nature of the fallout from over-water shots. There was some indirect evidence that the fallout 50 nautical miles from Shot 2 arrived as a fine mist or aerosol.

(f) Time and rate of arrival of fallout were documented only within the atolls by Project 2.5a. However, limited results on more distant islands were obtained for Shot 1. Arrival was characterized by a rapid rise to a peak followed by a decline which, in the measurement of gamma dose-rate, merged imperceptibly with radioactive decay. Material first arrived at approximately 1/2 hr after detonation and continued for 1-1/2 to 2 hr.

(g) A continuous 100 hr unshielded exposure after the detonation of a 15-MT device on land will result in a minimum free field total dose of 100 r over an area as large as 25,000 sq mi.

(h) The development of an experimental model has provided a means of reconstructing fallout patterns using limited gamma field data and a comprehensive analysis of the meteorological situation as applied to particle trajectories.

Conclusions as to the usefulness of free-floating buoy stations for

[redacted]

documenting fallout can also be drawn. Contrary to the results obtained at IVY, the applicability of this method without modification to superweapon tests appears questionable. Late changes in the prediction of winds aloft induced uncertainties in shot scheduling of an unprecedented nature at CASTLE defeating efforts to mount any operations requiring advanced timing of the order of 24 to 48 hr. However, in one of the two instances where buoys were in place at detonation, valuable and otherwise unavailable data were obtained. In general, modifications of the technique are indicated prior to use at any future weapons' test, particularly superweapons.

7.4 RECOMMENDATIONS

Knowledge of the geometry of the source cloud and the manner in which radioactivity is associated with it has been shown to be of major importance in the prediction of the fallout. More detailed study of the cloud geometry factor and of the particulate nature of fallout at future tests is recommended. Such studies will require cloud sampling of some type.

Continuous wind data to 48 hr post detonation with adequate satellite station coverage should be obtained at future tests where significant fallout is expected.

Re-evaluation of methods for documenting primary fallout patterns at the Pacific Proving Ground is recommended. This re-evaluation should take into account the increased importance of the fallout problem with reference to both operations and security.

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APPENDIX A

SHOT 4 OPERATION PLAN—BUOY PHASE, PROJECT 2.5a

A.1 PLANS AND PREPARATION

Ships will load at Eniwetok according to the "Union Schedule of Events" and be ready for laying operations by the eve of U-3. They will proceed late U-2 in time to lay first buoy of COMPLETE ARRAY at 0200 on U-1, sea conditions permitting. (See CTG 7.3 ltr and accompanying chart.)*

A.2 LAYING PROCEDURE, COMPLETE ARRAY

(a) ATF 75 will lay western portion of array, as follows: P-1 clockwise through A-1; thence to T-2 counterclockwise through P-2; total buoys, 11; completion time, 2000, U-1.

(b) ATF 67 will lay eastern portion of array, as follows: F-2 counterclockwise through A-2; thence to B-1, clockwise through F-1. Total buoys 11; completion time, 2200, U-1.

NOTE: For buoy designations, see accompanying chart* "RADIO BUOY ARRAY FOR UNION, PROJECT 2.5a."

A.3 LAYING PROCEDURE, PARTIAL ARRAY

(a) ATF 75 will lay western portion, dropping first buoy no later than 1200 U-1: A-1 counterclockwise through P-1. Total buoys, 6; completion time, 2000, U-1.

(b) ATF 67 will lay eastern portion, dropping first buoy no later than 1200, U-1: A-2 clockwise through F-2. Total buoys 6; completion time, 2200, U-1.

A.4 PROCEDURE FOR ADVANCEMENT OR DELAY OF SHOT

(a) If, on U-3, a 24-hr advance in shot time is announced, loading can be completed and the complete array planted; if a 48-hr advance is announced loading of necessary buoys can be carried out and the partial array can be planted.

* Letters and enclosures are not included in this report.

[redacted]

(b) If placement of either the complete array or the partial array is proceeding and a 24-hr delay is announced, buoys already planted can be left to drift into new positions and additional buoys laid upstream at the proper time to round out the array.

(c) If placement of either array is proceeding and a delay of 48 hr or more is announced, buoys planted must be recovered. Either the complete or partial array may then be set out as time and circumstances permit.

A.5 <u>RECOVERY PROCEDURES</u>

Recovery operations are expected to commence on U day. Each ATF will recover own buoys, commencing with stations in probable fallout. If recovery ships themselves encounter fallout, they may retire and recover buoys in adjacent areas. Every effort should be made to recover the important stations as early as possible; however, if recovered buoys produce dangerously high radiation fields aboard ship, it may be necessary to break off and return to Eniwetok to off-load. The ships should then return immediately to recover remainder.

A.6 <u>MESSAGES TO ATF'S FROM CTG 7.3</u>

The following information should be included in messages to ATF's.

(a) Message to proceed to lay buoys should specify plan desired (complete or partial). Project will provide information.

(b) Message to proceed to recover buoys should indicate probable area of fallout by buoy designations. Project will provide information.

(c) Messages to ATF's to modify laying procedures on-site should include specific recommendations. Project will provide information.

A.7 <u>MESSAGES FROM ATF'S TO CTG 7.3</u>

(a) Each ship should report progress in laying operations every 4 hr. Stations and their positions should be reported along with the time of laying.

(b) During recovery, each ship should report progress every 4 hr, giving time and position, and radiation levels of sample bottles as determined by Project personnel aboard.

(c) Info CTG 7.1 on all messages.

[redacted]

APPENDIX B

GAMMA ACTIVITY MEASUREMENTS FOR THE TOTAL AND GUMMED PAPER COLLECTORS

TABLE B.1 - Gamma Activity Measurements, Shot 1, Total Collectors

Sample No.	Wt. of Solid (g)	Wt. of Liquid (ml)	Gamma Activity (mr/hr)		Date and Time Measured (PST)
			Liquid	Solid	
251.02	28.69	345	79.6	594.8	3/18/54 - 1400
251.03	803	14	8.1	144.5	3/18/54 - 1400
251.04	5.01	4	1.8	65.7	3/18/54 - 1400
251.05	1.61	6	0.91	27.7	3/18/54 - 1400
251.06	1.17	0	0	2.9	3/18/54 - 1400
251.07	0	120	0.9	0	3/18/54 - 1400
251.08	1.25	138	0.13	1.3	3/18/54 - 1400
251.10	3.58	124	0.23	0.96	3/18/54 - 1400
250.04	0.26	40	0.96	7.2	3/18/54 - 1400
250.05	0.14	78	0.58	3.5	3/18/54 - 1400
250.18	0	55	0.13	0.35	3/18/54 - 1400
250.22	0	16	0.058	0.31	3/18/54 - 1400
250.24	0.21	82	0.40	0.64	3/18/54 - 1400

[redacted] A

TABLE B.2 - Gamma Activity Measurements, Shot 1, Gummed Paper Collectors

Sample No.	Gamma Activity (mr/hr)	Date and Time Measured (PDT)
251.03	20.3	4/28/54 - 1240
251.07	1.2	4/28/54 - 1240
251.08	1.0	4/28/54 - 1240
250.05	4.3	4/28/54 - 1240
250.06	3.3	4/28/54 - 1240
250.17	2.3	4/28/54 - 1240
250.22	1.9	4/28/54 - 1240

TABLE B.3 - Gamma Activity Measurements, Shot 1, Gummed Paper Collectors

Sample No.	Gamma Activity (mr/hr)	Date and Time Measured (PST)
1-S-DW$_o$	0.0008	3/18/54 - 1400
1-S-DW	0.0012	3/18/54 - 1400
1-S-DWJ	0.0069	3/18/54 - 1400
1-S-DWK	0.0021	3/18/54 - 1400
1-S-DWL	0.0021	3/18/54 - 1400

[redacted]

TABLE B.4 - Gamma Activity Measurements, Shot 2, Gummed Paper Collectors

Sample No.	Bearing (Degrees True)	Distance from GZ (nautical miles)	Gamma Activity (mr/hr)	Date and Time Measured (PST)
A_4	352	43	1200	3/27/54 - 1930
O_4	247	34	5	3/27/54 - 2045
P_4	271	34	20	3/28/54 - 1820
Q_4	295	34	280	3/28/54 - 0845
R_4	308	36	5000	3/28/54 - 1200
T_4	337	43	2200	3/28/54 - 1300
A_5	347	52	1400	3/28/54 - 1520
D_5	054	53	0	- -
E_5	075	53	0	- -
F_5	095	53	0	- -
G_5	115	53	0	- -

[redacted]

TABLE B.5 - Gamma Activity Measurements, Shot 3, Total Collectors

Sample No.	Vol. of Liquid (ml)	Wt. of Solid (g)	Gamma Activity (mr/hr)		Date and Time Measured (PST)
			Solid	Liquid	
251.02	-	-	300	-	4/8/54 - 1000
251.03	1785	0	0	3.28	4/15/54 - 1500
251.04-1	1630	0.34	0.17	0.41	4/15/54 - 1500
251.04-2	1475	0.34	0.16	0.33	4/15/54 - 1500
251.04-3	2130	0	0	0.25	4/15/54 - 1500
251.08	1150	2.30	0.37	0.42	4/15/54 - 1500
251.10	325	3.44	0.17	0.39	4/15/54 - 1500
250.05	-	-	275	-	4/8/54 - 1630
250.06	1665	0	0	9.92	4/15/54 - 1500
250.07	-	-	150	-	4/8/54 - 1530
250.08-1	110	0.12	3.37	3.55	4/15/54 - 1500
250.08-2	170	0	0	2.45	4/15/54 - 1500
250.09	615	0	0	0.59	4/15/54 - 1500
250.12	75	0	0	0.11	4/15/54 - 1500
250.13	245	0	0	0.19	4/15/54 - 1500
250.14-1	235	0	0	0.28	4/15/54 - 1500
250.14-2	320	0	0	0.41	4/15/54 - 1500
250.15-1	380	0	0	0.21	4/15/54 - 1500
250.15-2	248	0	0	0.41	4/15/54 - 1500
250.16	260	0	0	7.32	4/15/54 - 1500
250.17	-	-	280	-	4/12/54 - 0900
250.18-1	515	2.81	51.8	134.6	4/15/54 - 1500
250.18-2	560	0	0	19.3	4/15/54 - 1500
250.18-3	365	0	0	6.94	4/15/54 - 1500
250.19	938	0	0	1.11	4/15/54 - 1500
250.22	915	0	0	0.92	4/15/54 - 1500

[redacted]

TABLE B.6 - Gamma Activity Measurements, Shot 3, Gummed Paper Collectors

Sample No.	Gamma Activity (mr/hr)	Date and Time Measured(PST)
251.02	165	4/12/54 - 0900
251.03	32	4/12/54 - 0900
251.10	3	4/12/54 - 0900
250.05	160	4/12/54 - 0900
250.06	17.7	4/15/54 - 1500
250.07	37.9	4/15/54 - 1500
250.16	29.4	4/15/54 - 1500
250.17	155.5	4/15/54 - 1500
250.18	90.7	4/15/54 - 1500
250.19	1.06	4/15/54 - 1500

[redacted]

TABLE B.7 - Gamma Activity Measurements, Shot 4, Total Collectors

Sample No.	Total Vol. (ml)	Wt. Solid (g)	Gamma Activity (mr/hr) Solid	Date and Time Measured (PDT)	Gamma Activity (mr/hr) Liquid	Date and Time Measured (PDT)
251.03-1	11	0.234	28.9	5/5/54 - 0900	6.65	5/4/54 - 1600
251.03-2	9.4	0.432	22.5	5/5/54 - 0900	4.64	5/4/54 - 1600
251.03-3	11.4	0.332	27.0	5/5/54 - 0900	4.82	5/4/54 - 1600
251.03-4	22	0.345	28.9	5/6/54 - 1100	6.51	5/5/54 - 1600
251.04-1	250	9.18	0.19	5/5/54 - 0900	3.08	5/4/54 - 1600
251.04-2	1680	77.8	0.48	5/6/54 - 0900	0.30	5/7/54 - 1000
251.05(a)	370	0.324	0.84	5/6/54 - 0900	0.64	5/5/54 - 1500
250.05-1	450	0	0		44.7	5/4/54 - 1500
250.05-2	370	0	0		29.3	5/4/54 - 1500
250.07	288	0	0		0.24	5/4/54 - 1500
250.18-1	33	0	0		0.043	5/4/54 - 1600
250.18-2	133	0	0		0.35	5/4/54 - 1500
250.19	124	0	0		1.93	5/3/54 - 1500
250.22-1	22	0	0		0.27	5/4/54 - 1500
250.22-2	238	0	0		0.12	5/4/54 - 1500
Coca-1	585	0	0		0.27	5/4/54 - 1600
Coca-2	25	0	0		0.178	5/4/54 - 1500
Coca-3	25	0	0		0.25	5/3/54 - 1500
Coca-4	19	0	0		0.26	5/4/54 - 1600
Coca-5	211	0	0		0.62	5/4/54 - 1500
Coca-6	137	0	0		1.03	5/4/54 - 1600
Coca-7	450	0.345	1.45	5/6/54 - 0900	0.88	5/5/54 - 1500

(a) Three samples combined.

[redacted]

TABLE B.8 - Gamma Activity Measurements, Shot 4, Gummed Paper Collectors

Sample No.	Gamma Activity (mr/hr)	Date and Time Measured(PDT)
251.05	2.81	5/5/54 - 1500
250.05-1	145	5/5/54 - 1500
250.05-2	115.3	5/5/54 - 1500
250.07	0.54	5/5/54 - 1500
250.19	1.07	5/5/54 - 1500
250.22-1	1.14	5/5/54 - 1500
250.22-2	0.37	5/5/54 - 1500

[redacted]

TABLE B.9 - Gamma Activity Measurements, Shot 6, Total Collectors

Sample No.	Total Volume (ml)	Wt. of Solid (g)	Gamma Activity (mr/hr)		Date and Time Measured(PDT)
			Solid	Liquid	
Alice-1	410	-	0	1.95	6/1/54 - 1300
Alice-2	610	0	0.478	2.76	6/3/54 - 1400
Alice-3	445	0	0	0.355	6/1/54 - 1300
Alice-4	460	0.081	0.356	0.816	6/3/54 - 1400
Alice-5	450	1.09	0.500	2.47	6/3/54 - 1400
Janet-1	332	5.53	0.360	0.0984	6/3/54 - 1400
Janet-2	275	4.31	0.328	0.0797	6/3/54 - 1400
Janet-3	250	4.37	0.382	0.0621	6/3/54 - 1400
Janet-4	415	0.072	0.241	0.171	6/3/54 - 1400
Janet-5	465	0.430	0.232	0.237	6/3/54 - 1400
Janet-6	455	1.35	0.424	0.220	6/3/54 - 1400
Leroy-1	725	0	0	0.0077	6/1/54 - 1300
Leroy-2	720	0	0	0.00579	6/1/54 - 1300
Leroy-3	725	0	0	0.00482	6/1/54 - 1300
Leroy-4	750	0	0	0.00482	6/1/54 - 1300
Leroy-5	760	0	0	0.00635	6/1/54 - 1300
Leroy-6	705	0	0	0.00482	6/1/54 - 1300
Leroy-7	815	0	0	0.00540	6/1/54 - 1300
Leroy-8	705	0	0	0.00500	6/1/54 - 1300
Nancy	305	0	0	0.149	6/1/54 - 1300
250.27	593	0	0	0.280	6/1/54 - 1300
250.28	655	0	0	0.0742	6/1/54 - 1300
250.30	660	0	0	0.0282	6/1/54 - 1300
250.32	450	0	0	0.322	6/1/54 - 1300
250.33	455	0	0	0.0685	6/1/54 - 1300
250.34	462	0	0	0.117	6/1/54 - 1300
250.35	450	0	0	0.011	6/1/54 - 1300
250.36	350	0	0	1.11	6/1/54 - 1300
250.37-1	2110	0	0	0.00635	6/1/54 - 1300
250.37-2	1750	0	0	0.00715	6/1/54 - 1300
250.37-3	1500	0	0	0.0077	6/1/54 - 1300
250.39	930	0	0	0.0135	6/1/54 - 1300
250.41	935	0	0	0.0081	6/1/54 - 1300
250.47	875	0	0	0.0081	6/1/54 - 1300
250.48	1315	0	0	0.0154	6/1/54 - 1300
250.49-1	1520	0	0	0.00635	6/1/54 - 1300
250.49-2	1335	0	0	0.0054	6/1/54 - 1300

[redacted]

TABLE B.9 - Gamma Activity Measurements, Shot 6, Total Collectors (Cont.)

Sample No.	Total Volume (ml)	Wt. of Solid (g)	Gamma Activity (mr/hr)		Date and Time Measured(PDT)
			Solid	Liquid	
250.49-3	1310	0	0	0.00482	6/1/54 - 1300
250.49-4	780	0	0	0.0247	6/1/54 - 1300
250.49-5	1085	0	0	0.00425	6/1/54 - 1300
250.49-6	1470	0	0	0.0077	6/1/54 - 1300
250.50	1225	0	0	0.0164	6/1/54 - 1300
250.51	1110	0	0	0.00906	6/1/54 - 1300
250.54	1085	0	0	0.00925	6/1/54 - 1300
250.55	960	0	0	0.005	6/1/54 - 1300
250.58	765	0	0	0.00578	6/1/54 - 1300
Barge-1	1115	0	0	0.146	6/1/54 - 1300
Barge-2	1140	0	0	0.27	6/1/54 - 1300
Barge-3	1010	0	0	0.0151	6/1/54 - 1300
Barge-4	1050	0	0	0.139	6/1/54 - 1300
Mack-1	1915	0	0	0.0338	6/1/54 - 1300
Mack-2	1528	0	0	0.0278	6/1/54 - 1300
Oscar-1	710	0	0	0.0117	6/1/54 - 1300

[redacted]

APPENDIX C

PARTICLE SIZE DISTRIBUTION AND PERIOD OF FALLOUT DATA, SHOTS 1 AND 6

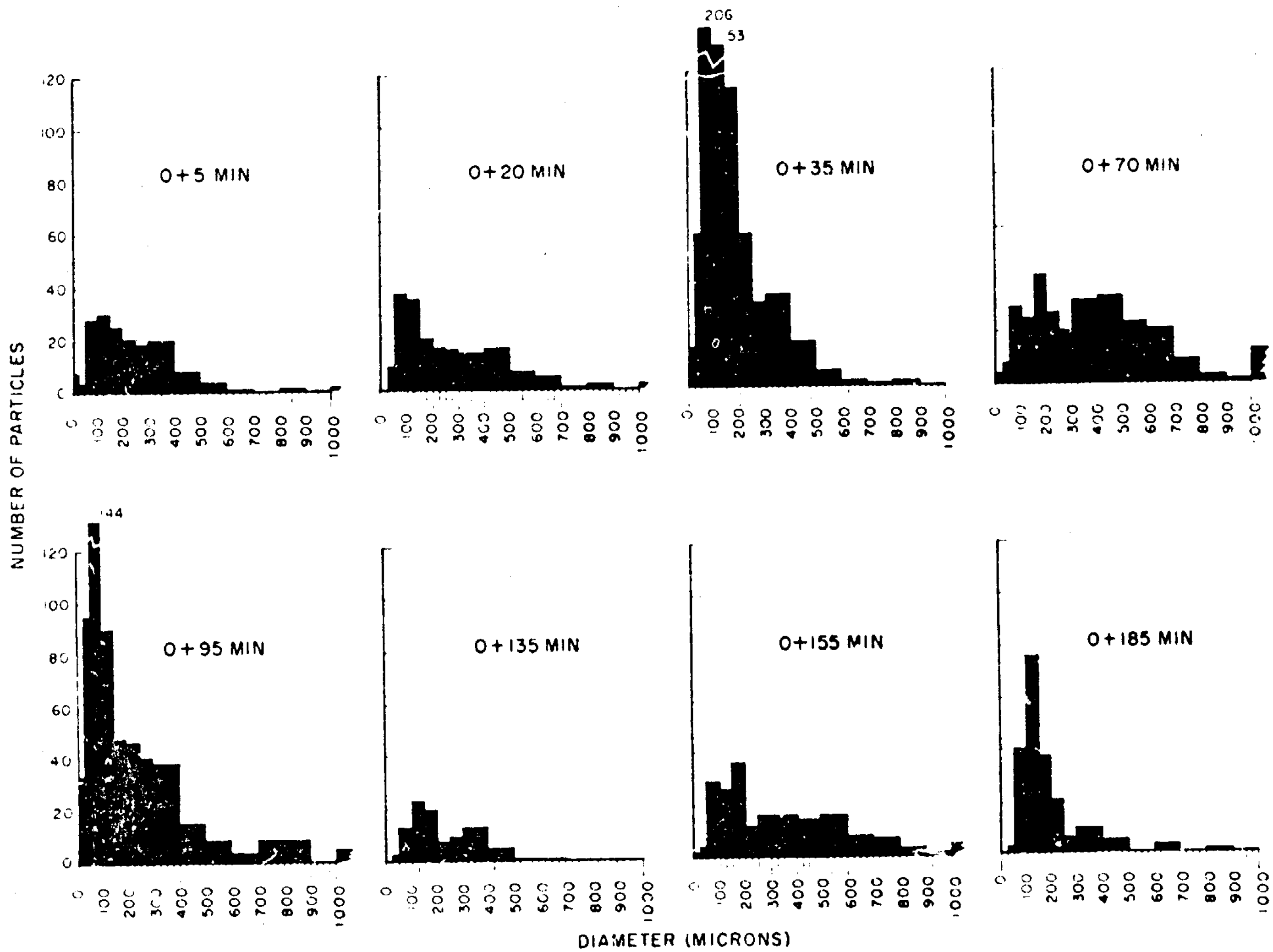

Fig. C.1 Shot 1 Particle Size Distribution, Station 250.04

[redacted]

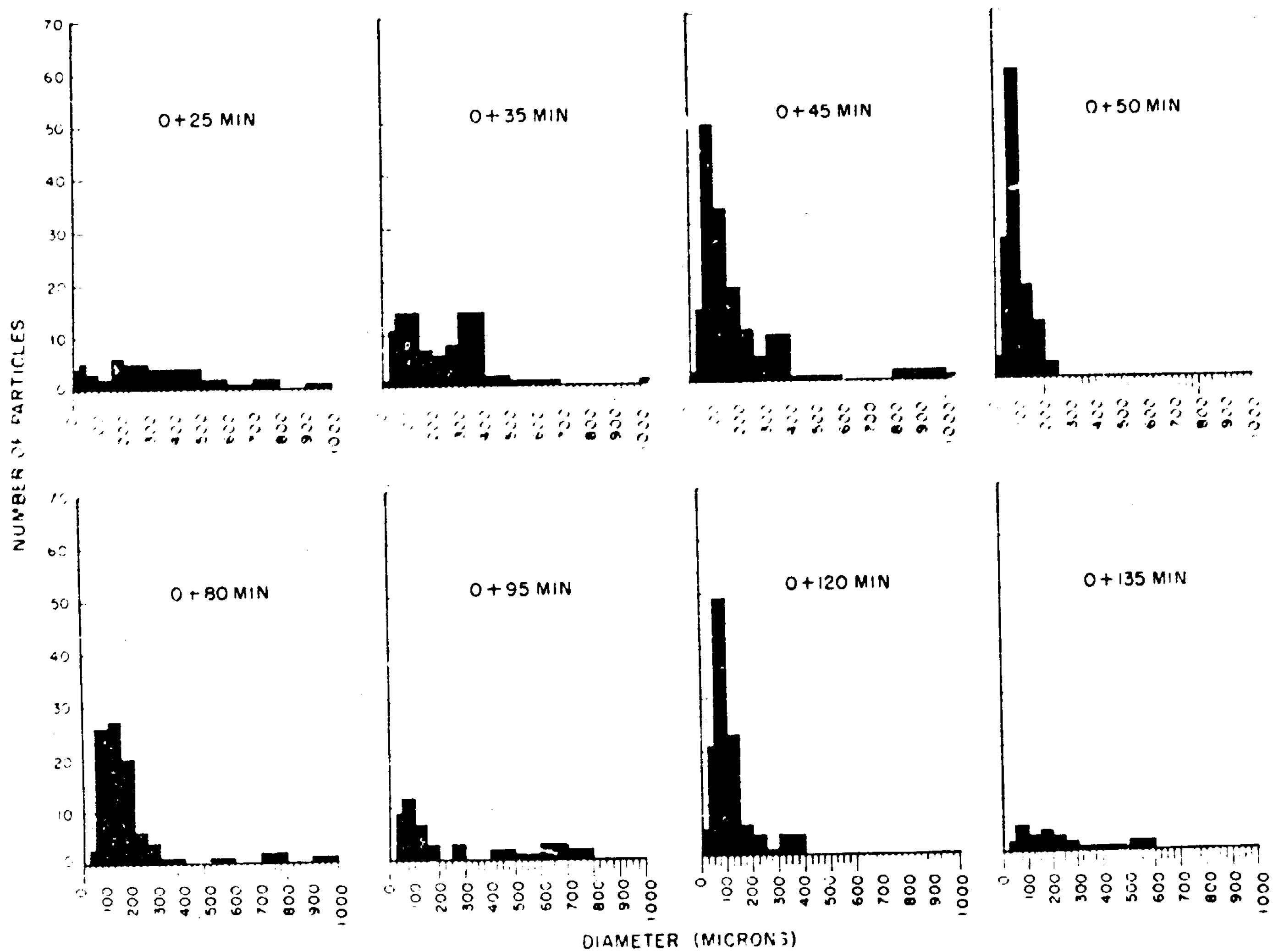

Fig. C.2 Shot 1 Particle Size Distribution, Station 250.06

[redacted]

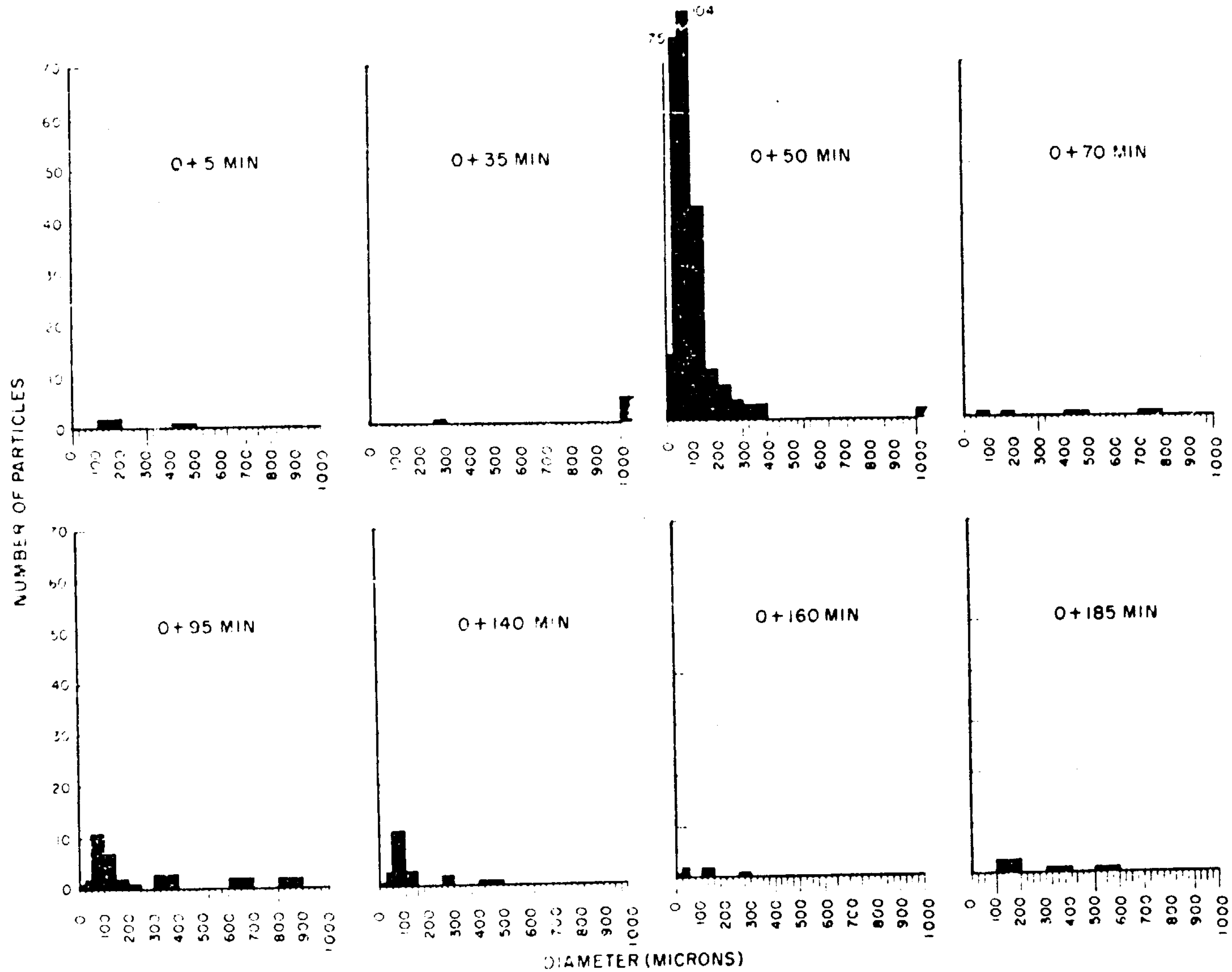

Fig. C.3 Shot 1 Particle Size Distribution, Station 250.22

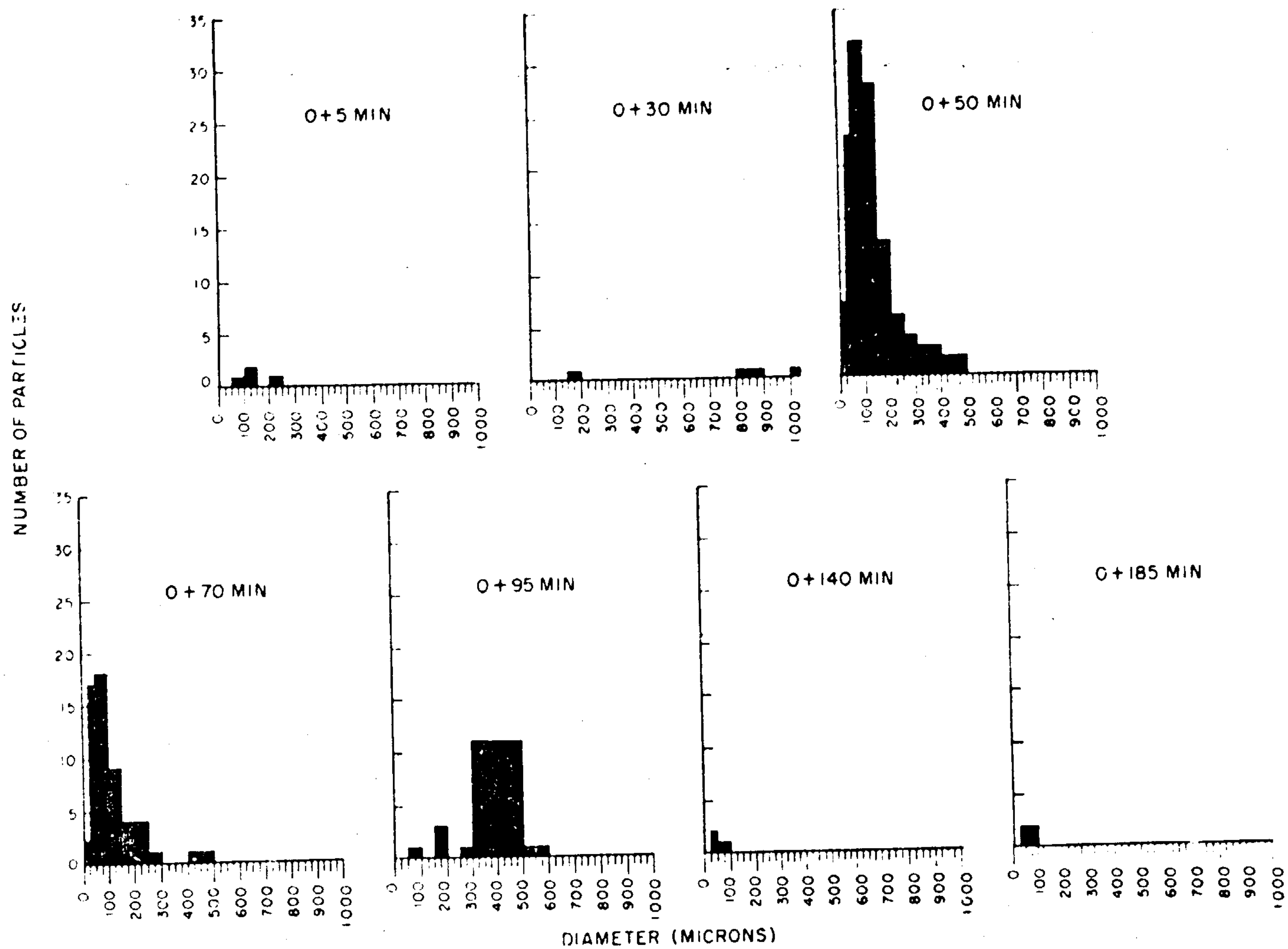

Fig. C.4 Shot 1 Particle Size Distribution, Station 250.24

[redacted]

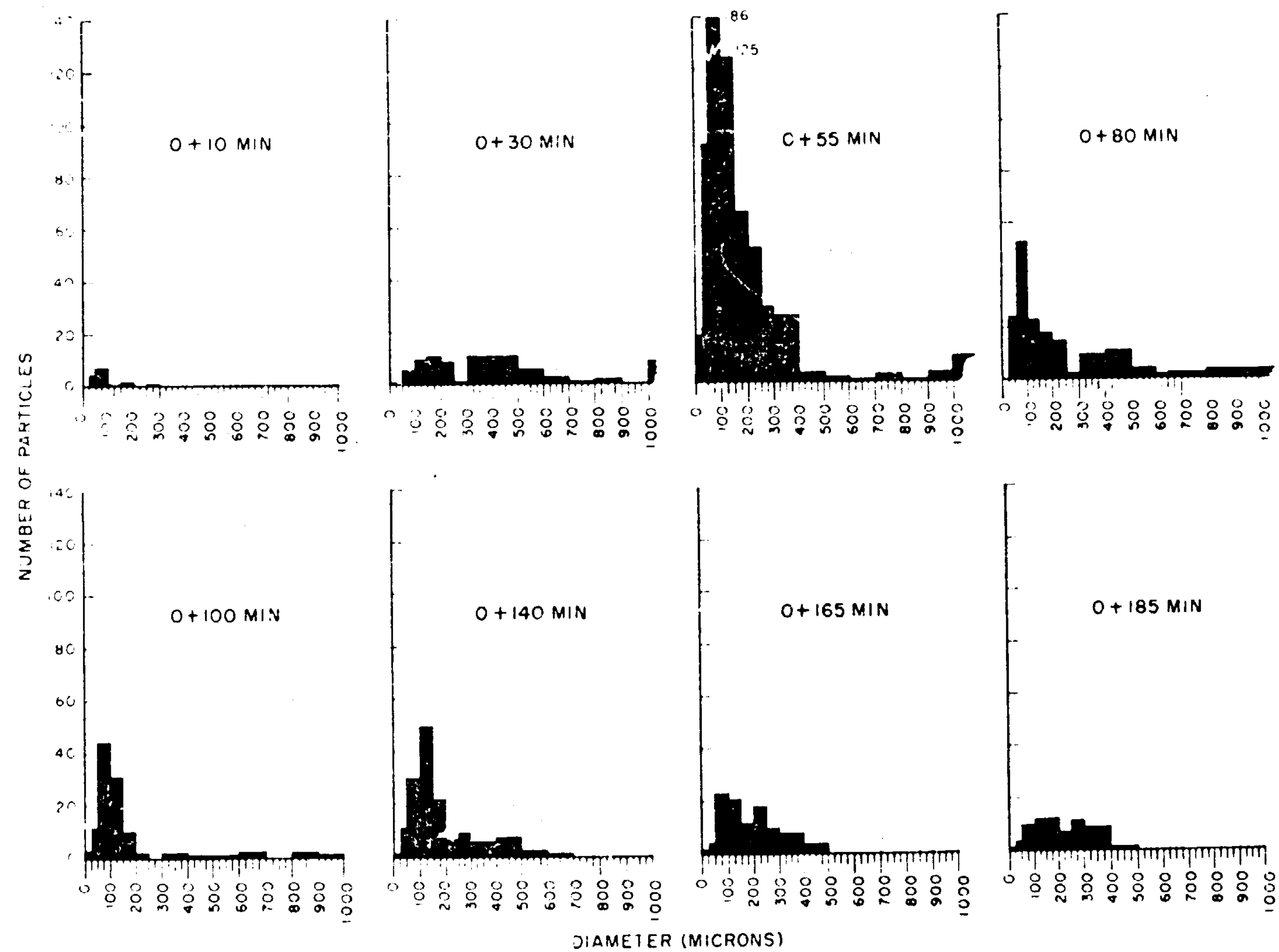

Fig. C.5 Shot 1 Particle Size Distribution, Station 251.04

[redacted]

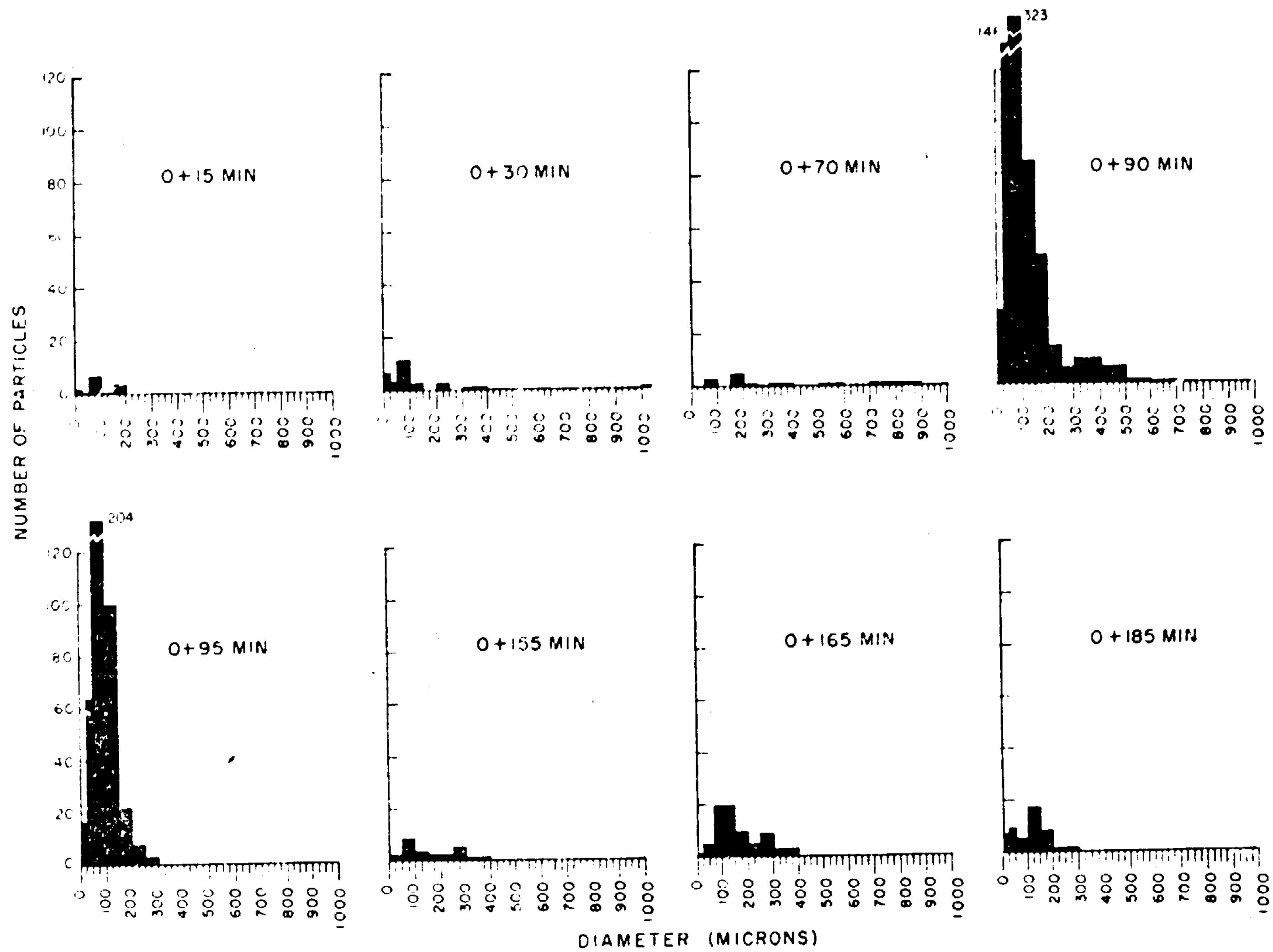

Fig. C.6 Shot 1 Particle Size Distribution, Station 251.06

[redacted]

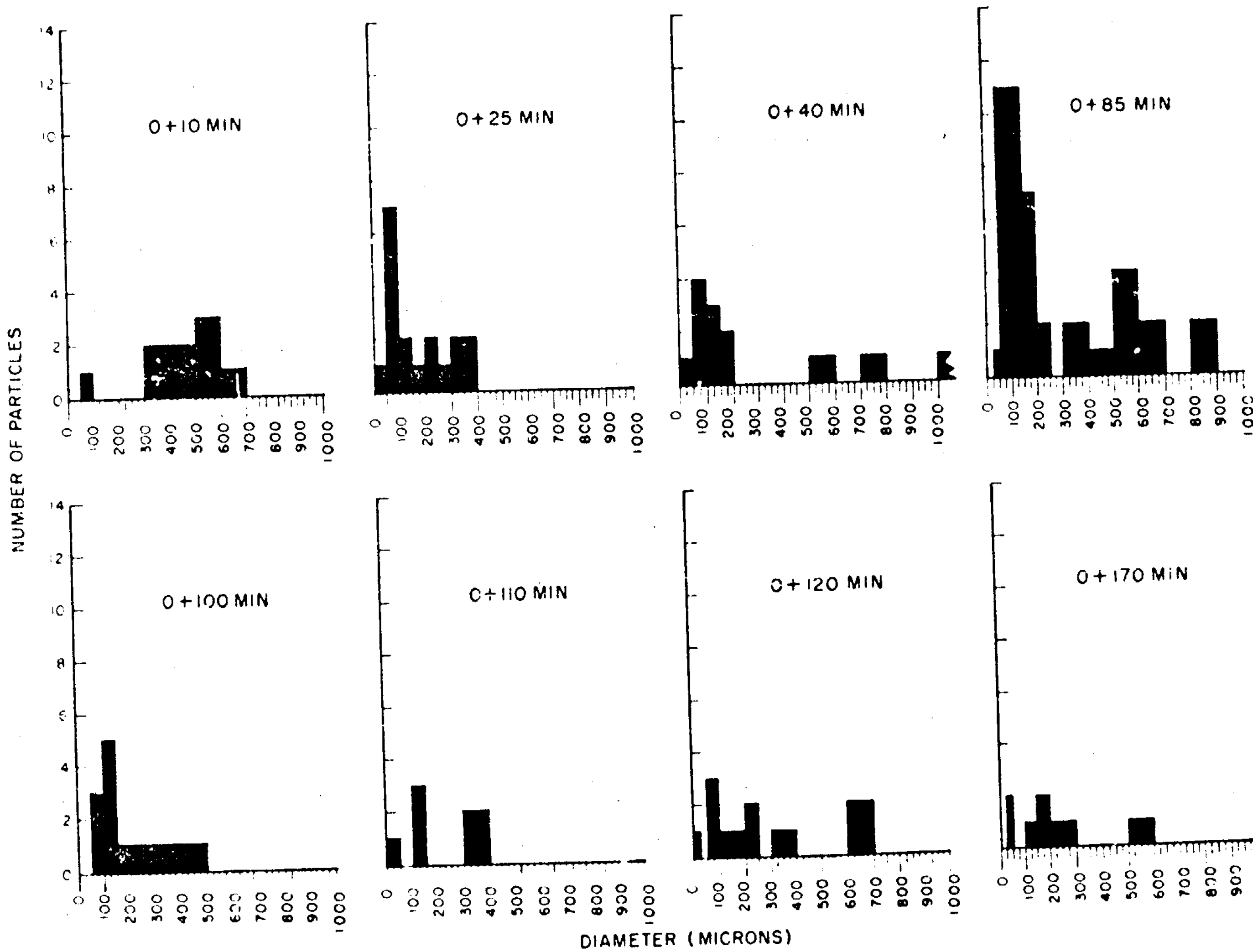

Fig. C.7 Shot 1 Particle Size Distribution, Station 251.10

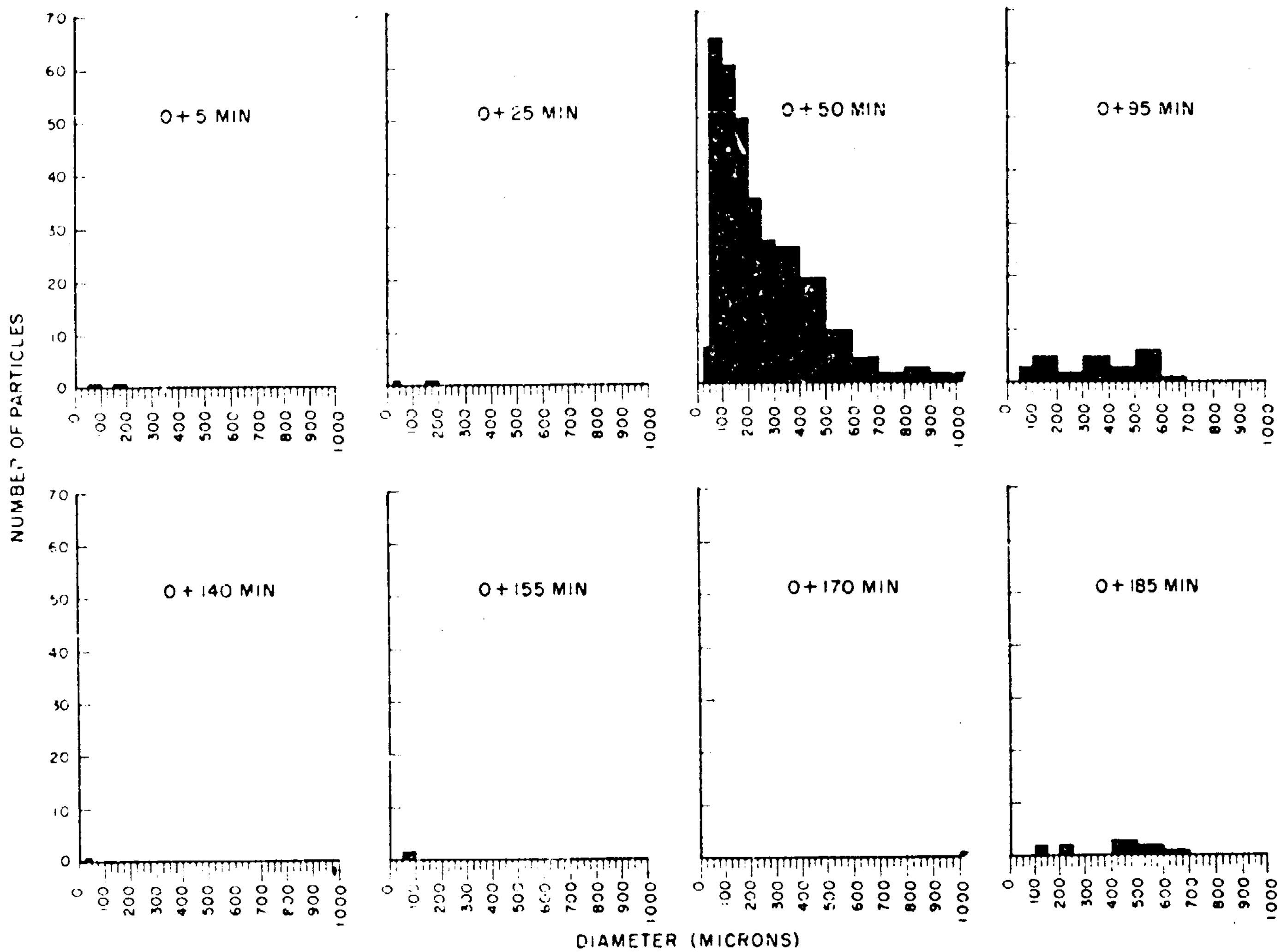

Fig. C.8 Shot 6, Particle Size Distribution, Station Alice

[redacted] A

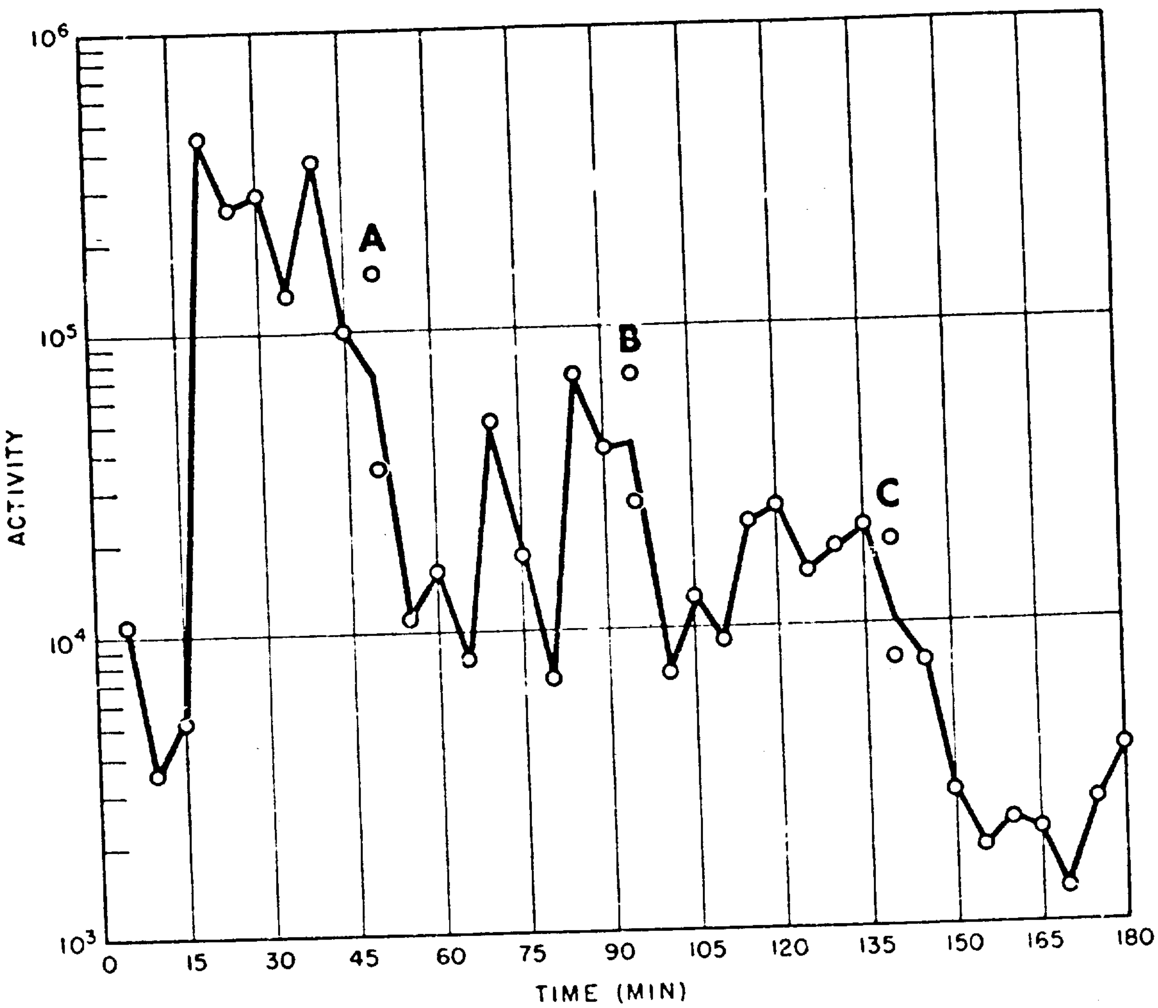

Fig. C.9 Shot 1, Time of Arrival and Period of Fallout, Station 250.05 (A,B, and C as in text p. 69)

[redacted]

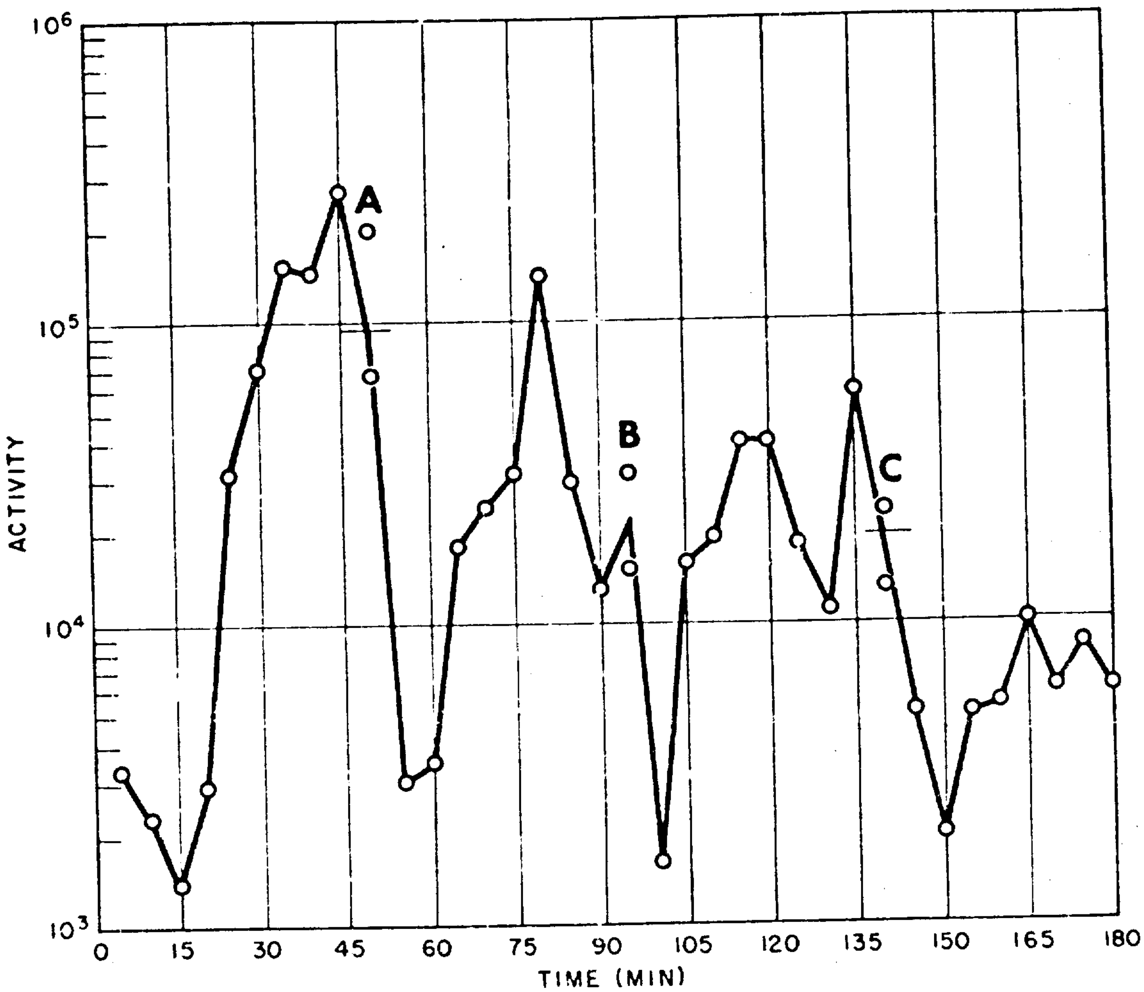

Fig. C.10 Shot 1, Time of Arrival and Period of Fallout, Station 250.06

[redacted]

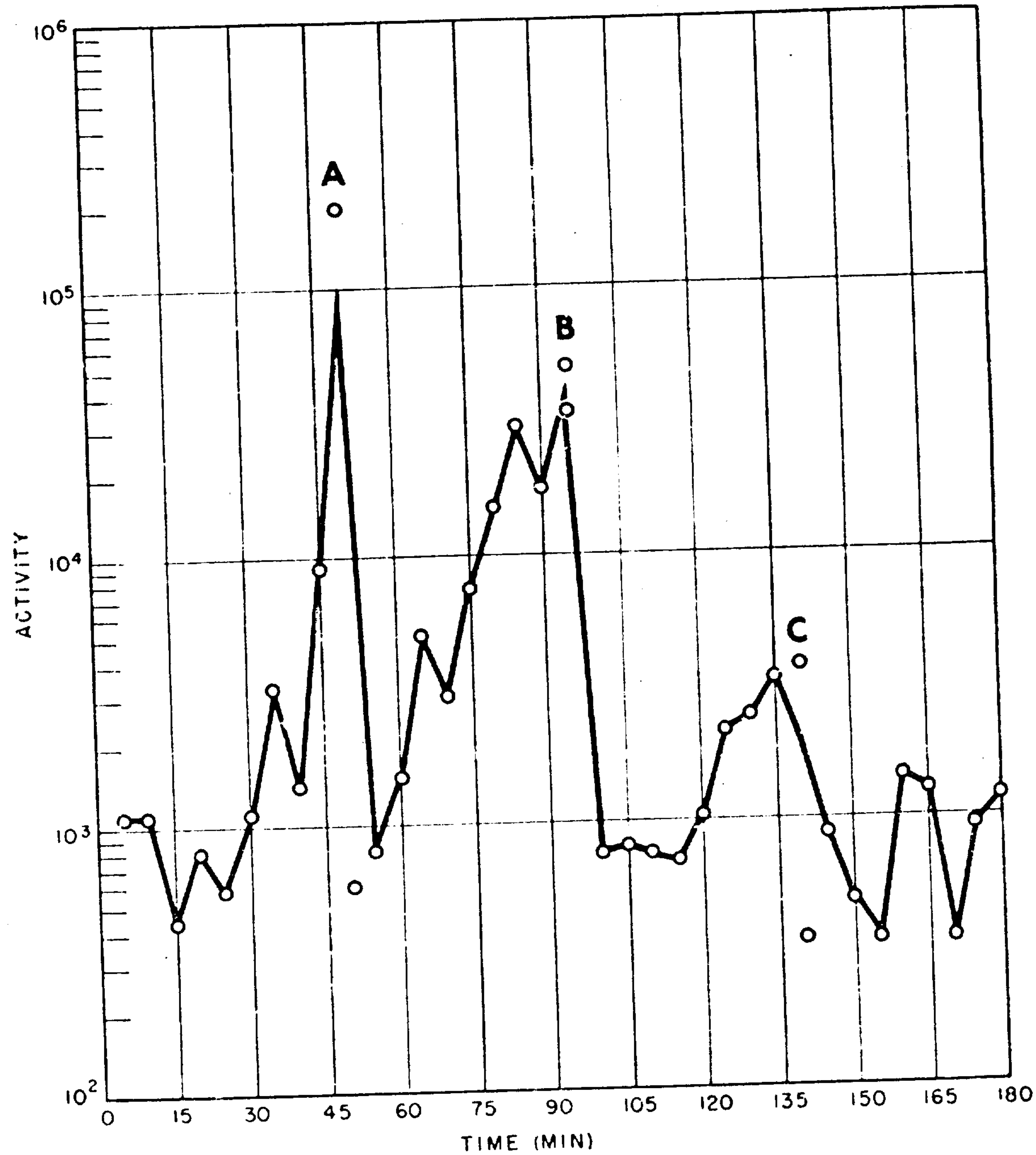

Fig. C.11 Shot 1, Time of Arrival and Period of Fallout, Station 250.22

[redacted]

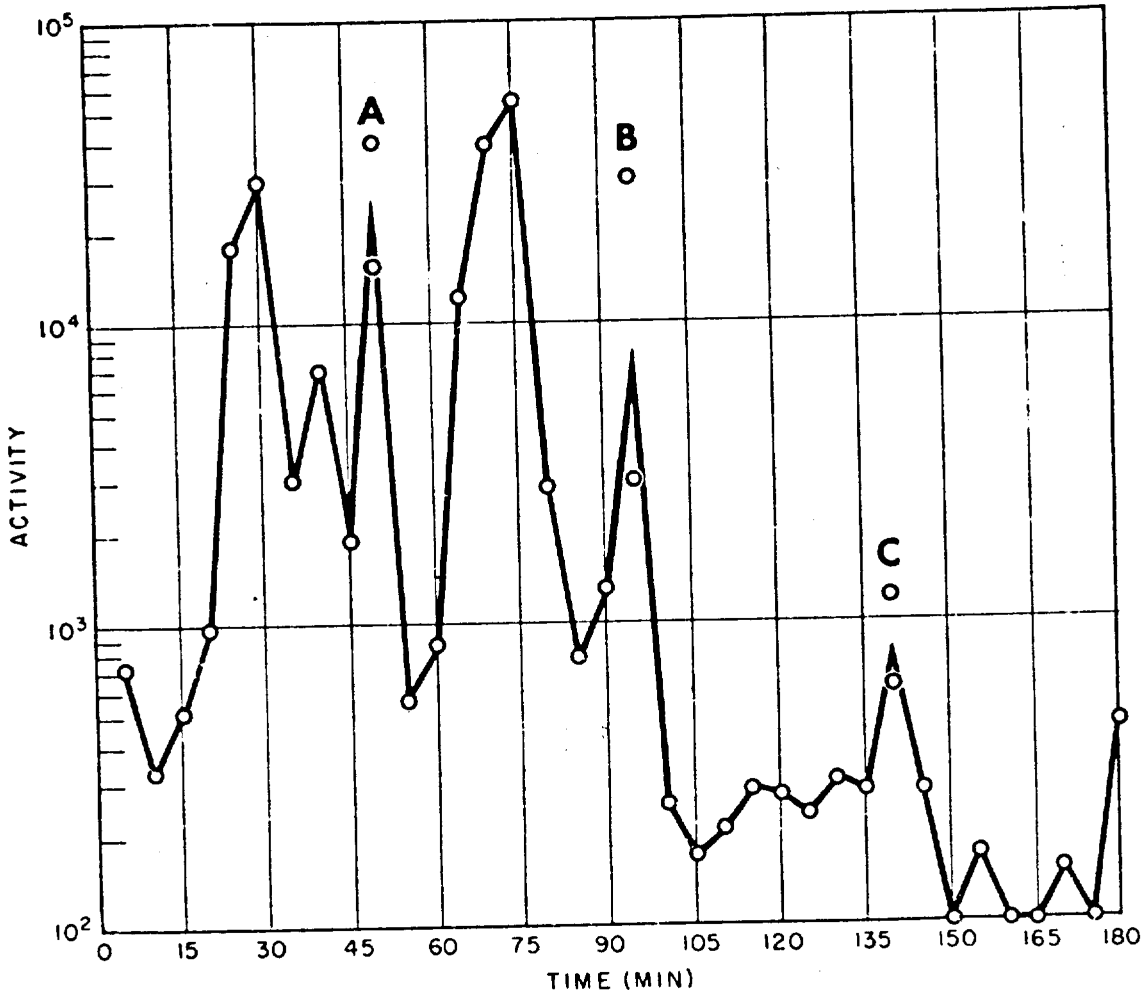

Fig. C.12 Shot 1, Time of Arrival and Period of Fallout, Station 250.24

[redacted]

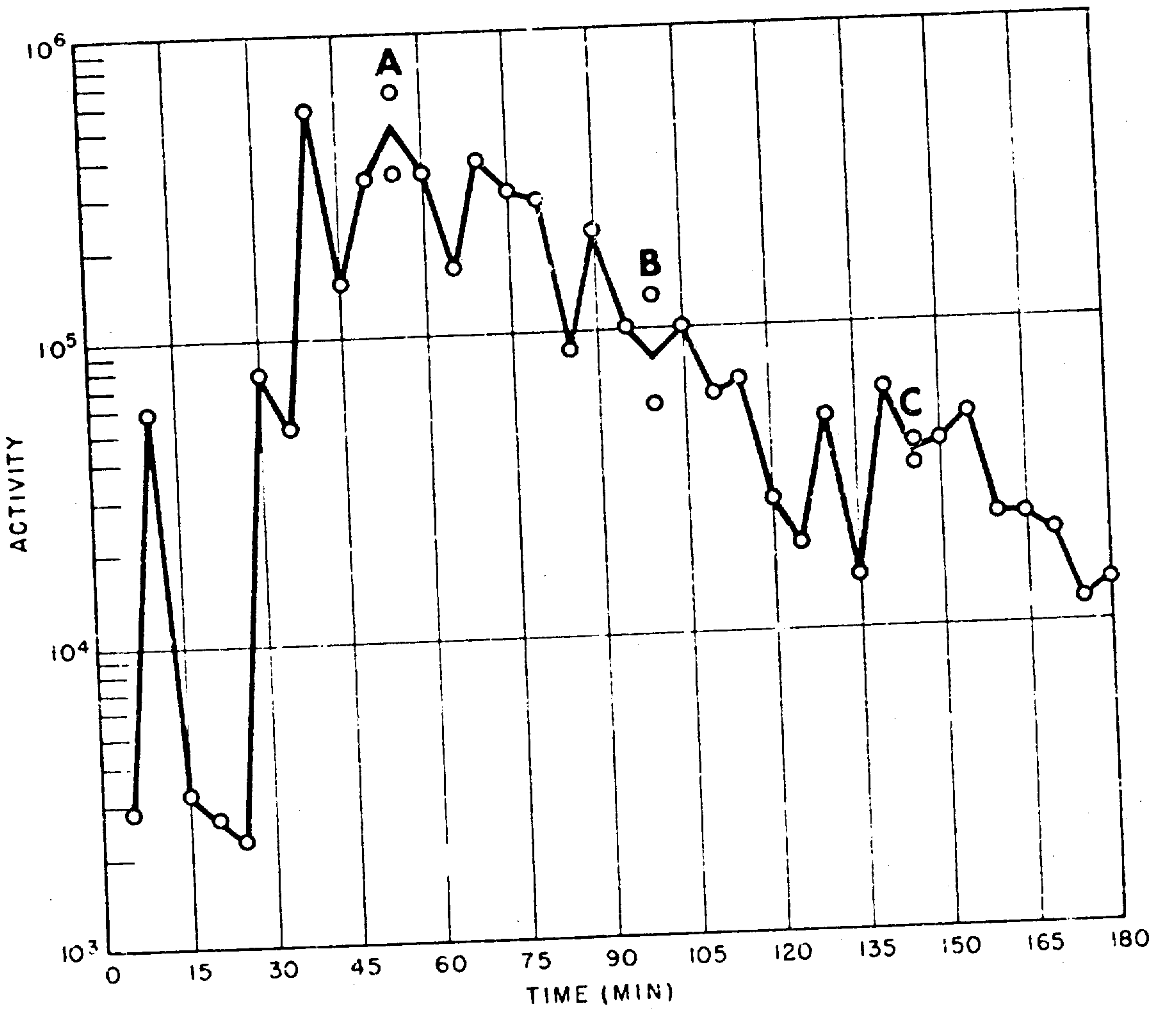

Fig. C.13 Shot 1, Time of Arrival and Period of Fallout, Station 251.04

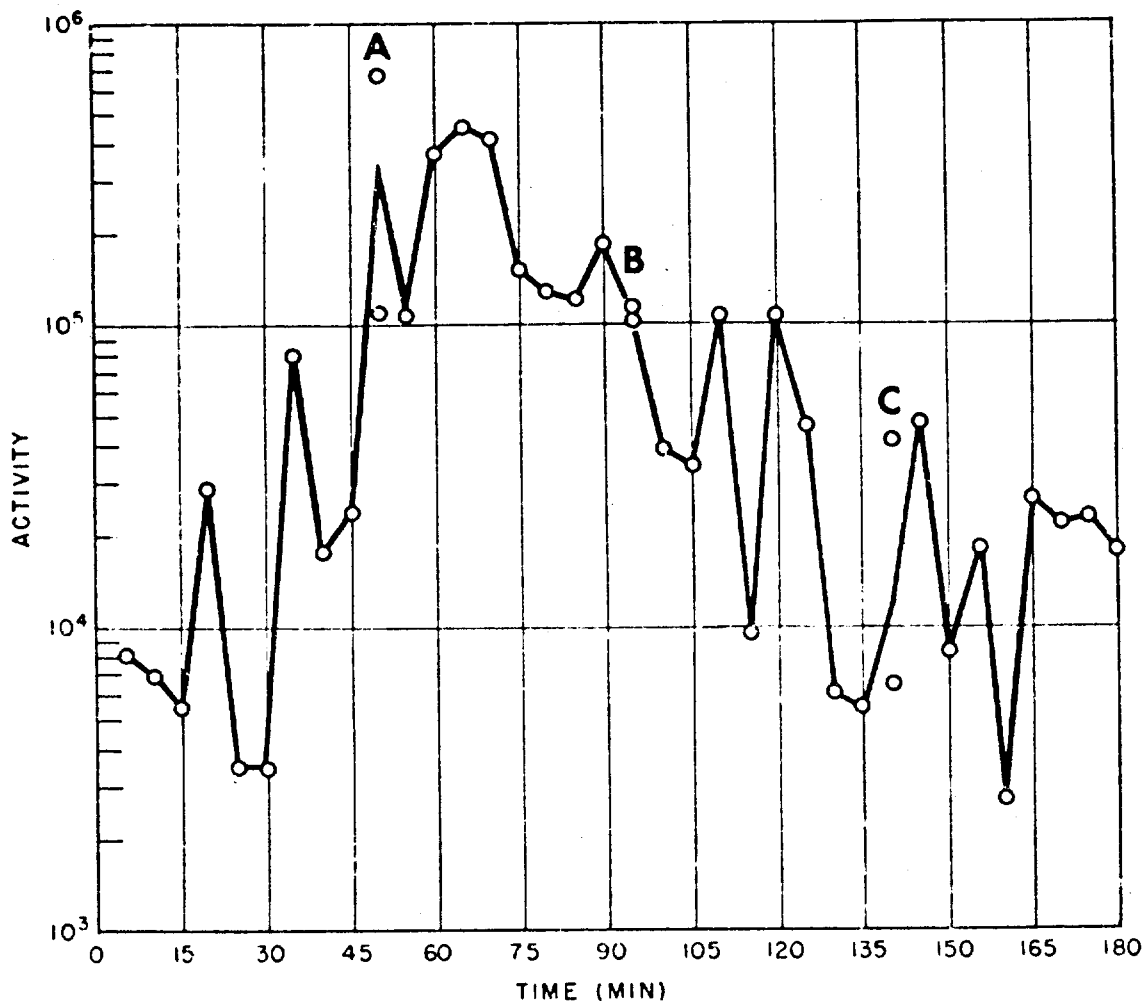

Fig. C.14 Shot 1, Time of Arrival and Period of Fallout, Station 251.05

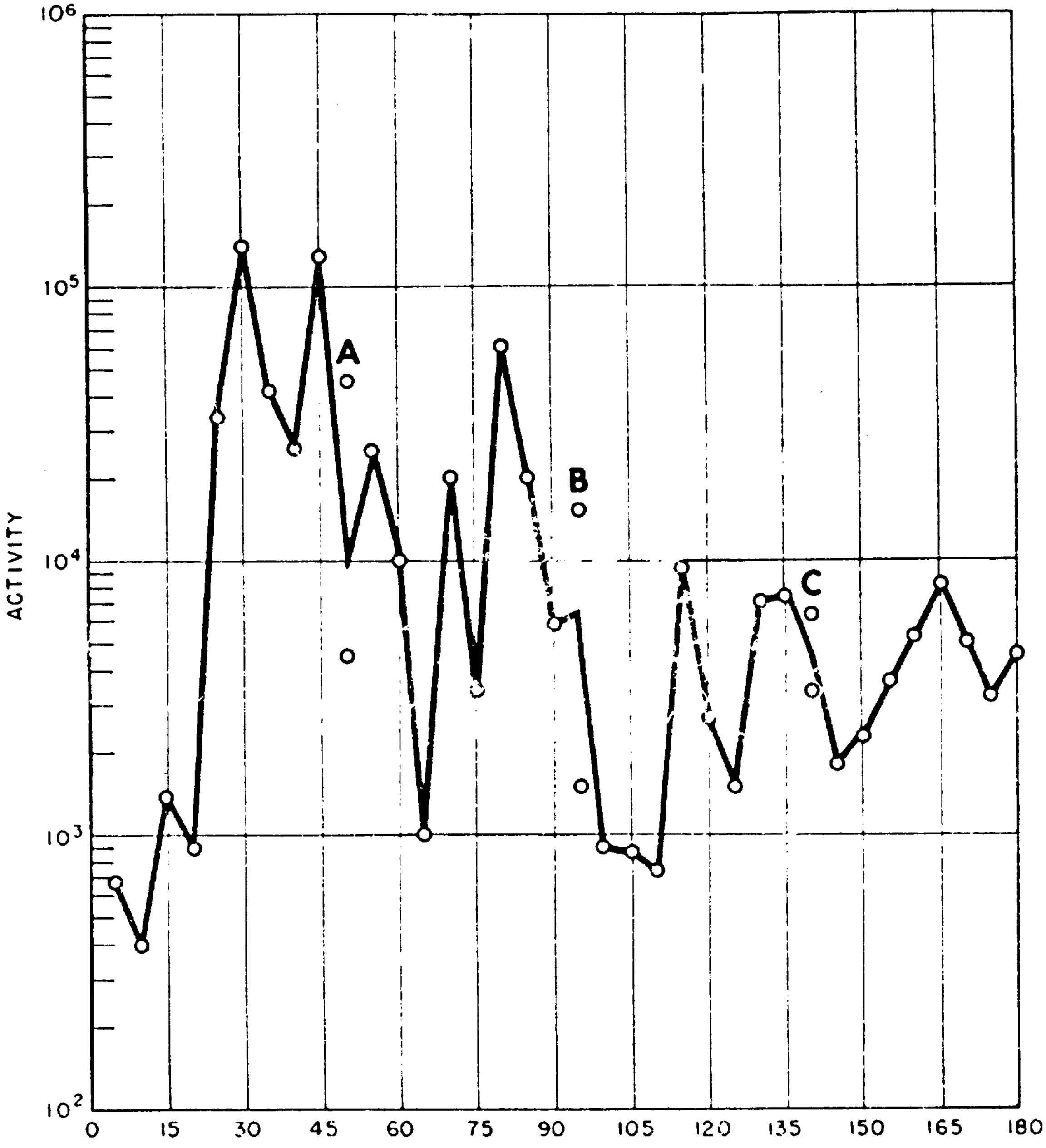

Fig. C.15 Shot 1, Time of Arrival and Period of
Fallout, Station 251.06

[redacted]

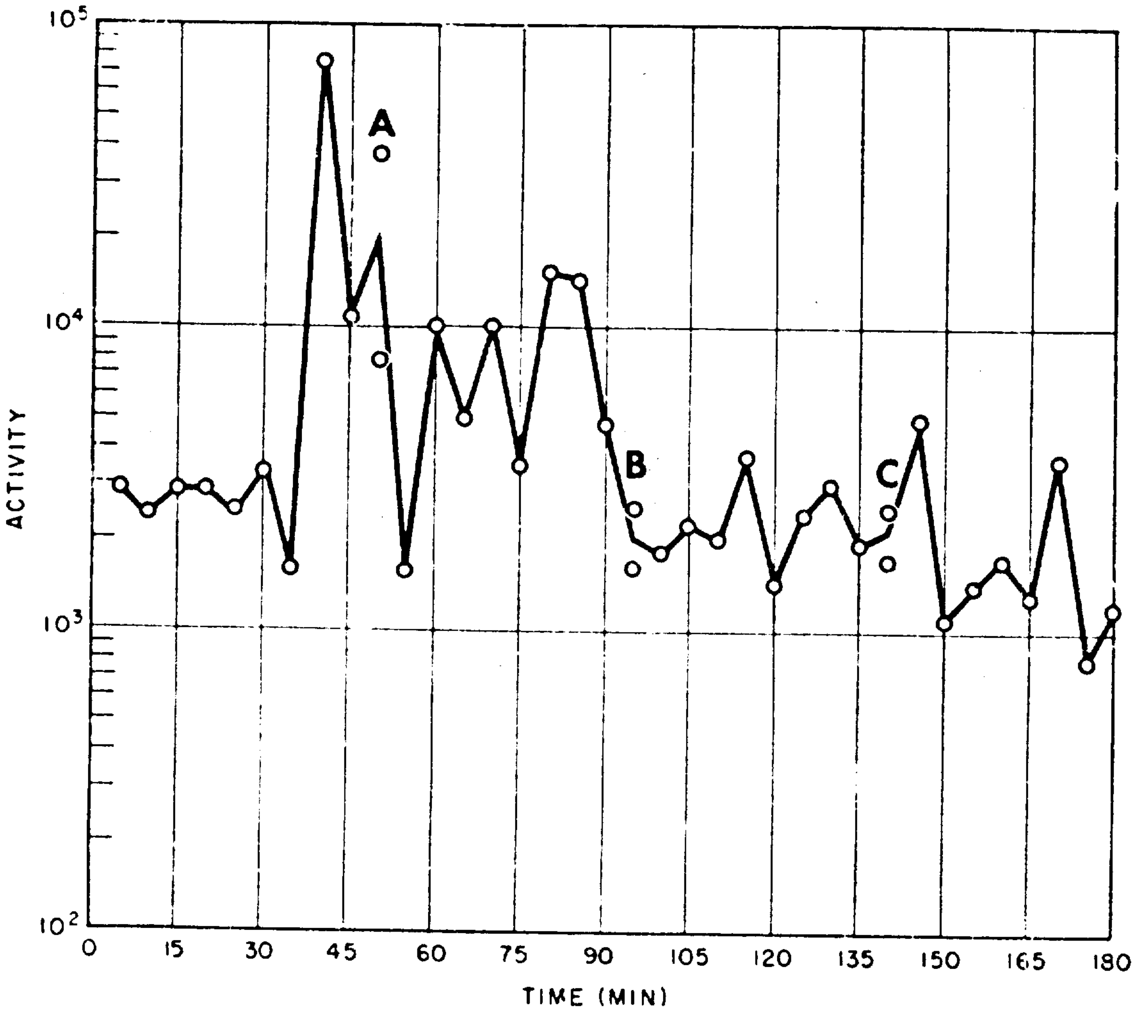

Fig. C.16 Shot 1, Time of Arrival and Period of Fallout, Station 251.10

[redacted]

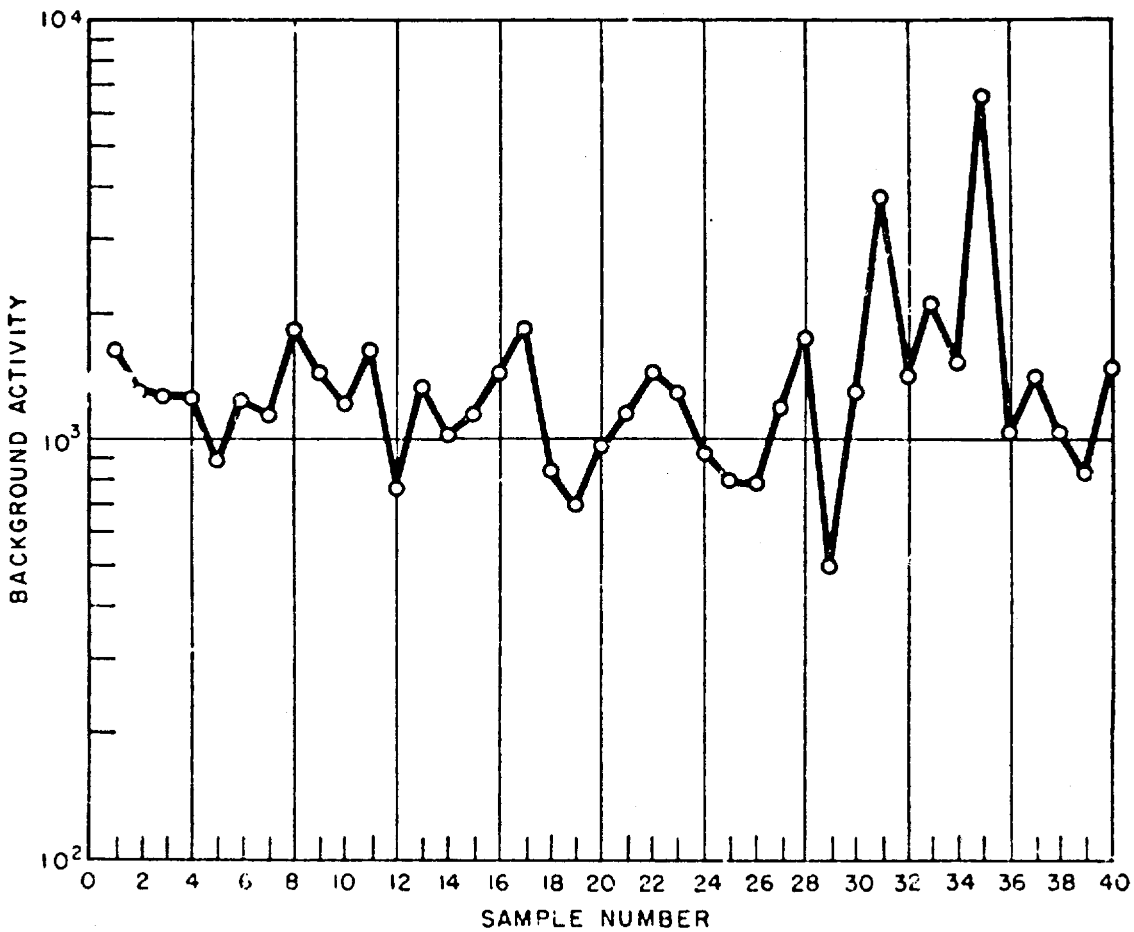

Fig. C.17 Example of Relative Background Activity, Station 251.09 (sampler exposed but did not operate)

[redacted]

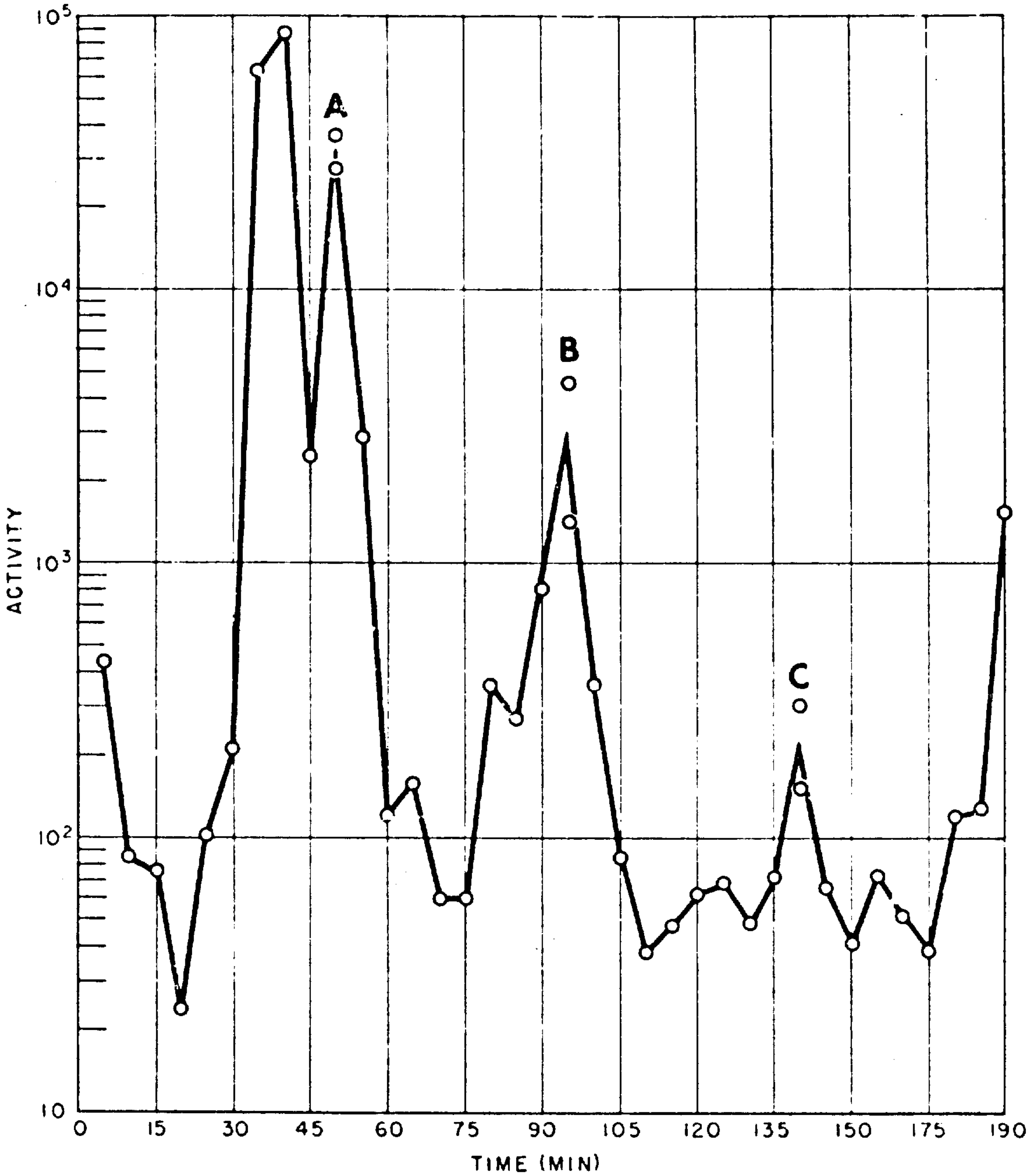

Fig. C.18 Shot 6, Time of Arrival and Period of Fallout, Station Alice

[redacted]

APPENDIX D

FALLOUT PARTICLE DENSITY, SHOT 1

TABLE D.1 - Differential Fallout Collector 250.04

Sample No.	Sampling Time min after ABD	Density (g/cu cm)	Average Diameter (μ)	γActivity (c/m)	Date Counted	Color
1	25	2.28	1480	53	7/20	white with orange tinge
2	40	2.05	1020	84	7/20	white
3	40	2.54	900	86	7/19	grayish white
4	50	2.24	580	89	7/20	white
5	55	2.22	730	210	7/20	white
6	75	2.42	1060	110	7/19	gray
7	80	2.26	810	230	7/19	white
8	85	2.52	350	21	7/20	white
9	90	2.52	750	47	7/23	white
10	95	2.18	675	502	7/20	white
11	100	2.17	550	66	7/19	white
12	105	2.10	500	40	7/21	white
13	110	2.24	630	0	7/21	white
14	125	2.19	590	105	7/21	white
15	130	2.41	540	64	7/21	white
16	135	2.22	260	19	7/21	white
17	130	1.78	490	13	7/19	white
18	140	2.18	350	44	7/21	white
19	140	2.35	590	84	7/21	white
20	140	2.21	530	231	7/21	white
21	145	2.23	310	34	7/21	white
22	145	2.40	480	36	7/21	white
23	145	2.04	650	106	7/21	white
24	150	2.38	340	61	7/22	white
25	160	2.27	380	64	7/22	white
26	160	1.94	700	99	7/23	white
27	160	2.38	515	62	7/23	white
28	165	1.65	620	66	7/23	white
29	165	2.10	375	2	7/23	white
30	170	2.67	570	13	7/19	white
31	175	2.32	325	44	7/19	white
32	185	2.20	325	24	7/19	white

[redacted]

TABLE D.2 - Differential Fallout Collector 250.17

Sample No.	Sampling Time (min after ABD)	Density (g/cu cm)	Average Diameter (μ)	γ Activity (c/m)	Date Counted	Color
1	5	2.42	800	61	7/28	grayish
2	10	2.52	820	461	7/28	white
3	10	2.50	830	13	7/28	white
4	10	2.39	460	26	7/28	white
5	15	2.22	330	163	7/28	white
6	15	2.66	840	55	7/28	gray
7	20	2.40	525	14	7/28	gray
8	25	2.51	480	27	7/29	gray
9	35	2.55	360	38	7/29	gray
10	40	2.46	260	0	7/29	gray
11	40	2.55	1750	20	7/29	white with brown tinge
12	40	2.52	480	0	7/29	white
13	45	2.44	680	54	7/29	white
14	50	2.37	425	6	7/29	white
15	50	2.33	350	0	7/29	white
16	50	2.36	610	0	7/29	white
17	50	2.54	320	0	7/28	white
18	50	2.01	900	127	7/29	white
19	50	2.71	440	4	7/28	white
20	50	2.38	640	0	7/28	white
21	95	1.95	560	0	7/28	white
22	110	2.47	600	10	7/28	white
23	135	2.47	530	13	7/28	white
24	135	2.49	770	5	7/28	white
25	160	2.45	300	17	7/29	white
26	175	2.34	470	2928	7/29	white

[redacted]

TABLE D.3 - Differential Fallout Collector 250.24

Sample No.	Sampling Time (min after ABD)	Density (g/cu cm)	Average Diameter (μ)	γ Activity (c/m)	Date Counted	Color
1	5	2.11	420	0	7/22	white
2	10	2.40	980	0	7/22	white
3	15	2.38	425	0	7/22	white
4	20	2.22	240	26	7/22	white
5	25	2.75	275	12	7/22	white
6	35	2.66	675	160	7/22	white
7	50	2.62	1410	146	7/23	white
8	60	2.46	335	0	7/23	white
9	65	2.38	220	0	7/23	white
10	65	2.54	535	33	7/23	white
11	65	2.55	440	42	7/23	white
12	65	2.60	340	43	7/23	white
13	65	2.59	250	65	7/23	white
14	65	2.48	250	44	7/23	white
15	65	2.36	590	141	7/23	white
16	80	2.58	200	7	7/23	white
17	90	2.45	270	31	7/23	white
18	150	2.05	310	24	7/23	white

[redacted]

APPENDIX E

PARTICLE FALLING RATES

The determination of the falling rates for the fallout particles was made by initially calculating the terminal velocities for particles at various altitudes. A selected range of particle diameters was used in making these calculations. The diameters considered were: 10, 25, 50, 75, 100, 150, 200, 250, 375, 500, 750, and 1000 μ. Terminal velocities for these particles were calculated for starting altitudes at 5000 ft increments from 0 to 100,000 ft. From these data the average rates of fall of the particles through 5000 ft increments of the atmosphere were determined.

The calculation of the terminal velocities involved the use of known laws of settling of suspended particles from gases. The types of flow which these particles undergo are divided into three regions: streamline, where viscous forces predominate; intermediate; and turbulent, where inertia forces predominate. In simplified form, the laws governing these types of flow are:[3]

Streamline motion,

$$v_m = K_S \left(\frac{\rho - \rho_o}{\rho_o}\right) d^2 \nu^{-1} \qquad (E.1)$$

Intermediate region,

$$v_m = K_I \left(\frac{\rho - \rho_o}{\rho_o}\right)^{2/3} \nu^{-1/3} d_o \qquad (E.2)$$

Turbulent region,

$$v_m = K_T \left(\frac{\rho - \rho_o}{\rho_o}\right)^{1/2} d^{1/2} \qquad (E.3)$$

v_m = terminal velocity

K = constant, for irregular quartz particles: $K_S = 36$, $K_I = 17.2$ and $K_T = 50$.

ρ = density of the particle

ρ_o = density of the fluid

d = true diameter

ν = kinematic viscosity = $\frac{\mu}{\rho_o}$

[redacted]

μ = absolute viscosity of the fluid

$$d_o = d - \varsigma d'$$

$$\varsigma = 0.279$$

$$d' = 3.3\left[\frac{\mu^2}{g\ \rho_o(\rho-\rho_o)}\right]^{1/3}$$ = limiting diameter to which the streamline law applies

g = acceleration due to gravity

The values for K_S, K_T and ρ were given as determined for irregular quartz particles, which for this application is more suitable than those values given for spherical particles. The value of K_I was determined by solving the Eqs. E.1 and E.2 at the point of transition (85 μ) from streamline motion to the intermediate region.[3]

The density of the particle was determined experimentally for actual fallout particles collected in the field (see Section 5.4). The density[8] of the air and the viscosity[13] of the air which is temperature dependent are shown in Table E.1. The values for the viscosity are based on temperature measurements taken in the Bikini area at Shot 1 time by the Task Force Weather Central. Temperature data were not taken for altitudes above 50,000 ft, so the temperature above that elevation was assumed to be isothermal.

Since choice of the applicable equation is dependent upon the type of motion experienced by particles falling through air, it was necessary to determine the limiting diameters to which the various laws apply. The expression for the limiting diameter to which the streamline law applies was given above. The expression for the intermediate region,

$$d' = 43.5\left[\frac{\mu^2}{g\ \rho_o(\rho-\rho_o)}\right]^{1/3}$$

was available from another source.[8] The calculated values for the limiting particle diameters at different altitudes for the two types of motion are plotted in Fig. E.1. These plots define the areas in which the various equations for the determination of terminal velocities are applicable. It is seen that for some of the particle sizes considered (100, 150, 200 μ) the terminal velocity calculations follow the intermediate law to the altitudes indicated and beyond that the streamline law. Also, for the particle sizes considered from 250 to 1000 μ in diameter, it is evident that the intermediate law only governs the terminal velocity determinations.

When the density of the fluid is small as compared to that of the particle, the buoyancy correction becomes negligible and Eq. E.1 takes the form,

$$v_m = \frac{K_S\,\rho\,d^2}{\mu}$$

Since the temperature above 50,000 ft was assumed to be isothermal, the viscosity of the air remains constant and the terminal velocity is proportional to the square of the diameter. Thus for a given particle

[redacted]

TABLE 2.1 - Viscosity, Temperature and Density of Air at Various Altitudes

Altitude (ft)	Temp (°C)	Viscosity[a] (poise)	Density[b] g/cu cm
0	26.7°C	[illegible].03 x 10^{-4}	12.24 x 10^{-4}
2000	21	1.79	11.50
4000	16.4	1.75	10.70
6000	13.8	1.75	10.00
8000	13.7	1.75	9.4
10000	9.1	1.73	8.8
12000	5.1	1.72	8.3
14000	2.7	1.7	7.8
16000	-1.9	1.7	7.3
18000	-4.6	1.68	6.8
20000	-8.7	1.65	6.40
25000	-18.8	1.63	5.5
30000	-31.8	1.56	4.7
35000	-4[illegible].2	1.5	3.8
40000	-56.7	1.45	3.05
45000	-67.8	1.4	2.45
50000	-76.7	1.34	1.95
55000	-80.4	1.34	1.55
60000	-80.4	1.34	1.20
65000	-80.4	1.34	0.96
70000	-80.4	1.34	0.76
75000	-80.4	1.34	0.60
80000	-80.4	1.34	0.48
85000	-80.4	1.34	0.37
90000	-80.4	1.34	0.30
95000	-80.4	1.34	0.24
100000	-80.4	1.34	0.19

(a) See Reference 13
(b) See Reference 8

diameter the terminal velocity becomes constant at a certain elevation; this elevation is dependent on the particle size as shown in Table 2.2.

The calculated values for the terminal velocities are tabulated in Table 2.2 and the average rates of fall are tabulated in Table 2.3.

[redacted]

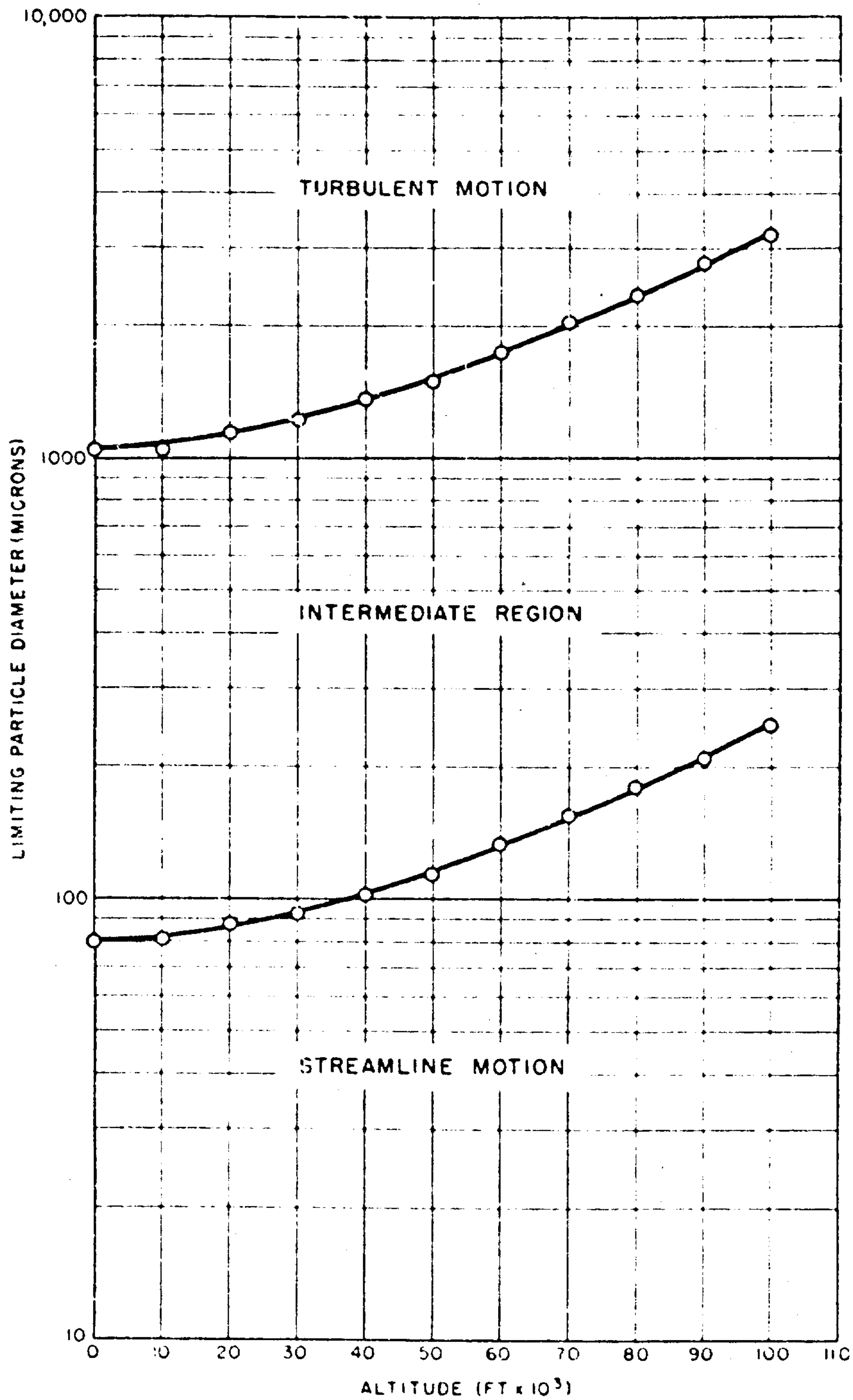

Fig. E.1 Areas of Applicability in Calculating Terminal Velocities

[redacted]

TABLE E.2 - Tabulated Terminal Velocities of Various Sized Particles Starting at Various Elevations

Altitude (ft)	Terminal Velocity (ft/hr) 10 μ	25 μ	50 μ	75 μ	100 μ	150 μ	200 μ	250 μ	375 μ	500 μ	750 μ	1000 μ
Surface	49.3	308	1230	2780	4480	7,375	10,300	13,100	20,400	27,600	42,000	56,500
2,000	55.8	349	1390	3140	4820	7,870	10,900	14,000	21,600	29,300	44,500	59,800
4,000	57.1	357	1430	3210	4950	8,100	11,100	14,400	22,200	30,100	45,800	61,600
6,000	57.2	358	1430	3220	5030	8,250	11,500	14,700	22,700	30,700	46,800	62,900
8,000	57.3	359	1440	3230	5100	8,330	11,700	14,900	23,100	31,300	47,700	64,100
10,000	57.7	361	1440	3250	5210	8,570	11,930	15,300	23,700	32,100	48,930	65,800
12,000	58.3	365	1460	3280	5320	8,760	12,200	15,660	24,300	31,900	50,100	67,300
14,000	59.0	369	1470	3320	5400	8,930	12,500	16,000	24,800	33,600	51,200	68,800
16,000	59.1	370	1480	3330	5520	9,140	12,800	16,400	25,400	34,500	52,500	70,600
18,000	59.6	373	1490	3360	5630	9,340	13,000	16,700	26,000	35,300	53,800	74,300
20,000	60.6	379	1520	3420	5760	9,570	13,400	17,200	26,700	36,200	55,200	74,300
25,000	61.1	382	1530	3440	6000	10,000	14,000	18,000	28,100	38,100	58,100	78,200
30,000	64.1	401	1600	3610	6370	10,700	15,000	19,300	30,000	40,700	62,200	83,700
35,000	67.1	420	1680	3780	6900	11,600	16,200	21,000	32,600	44,400	67,700	91,000
40,000	69.4	434	1730	3910	6940	12,400	17,400	22,500	35,200	48,000	73,400	98,800
45,000	71.4	446	1780	4020	7140	13,200	18,800	24,300	38,100	51,900	79,400	107,000
50,000	74.9	469	1870	4220	7500	14,300	20,300	26,300	41,300	56,400	86,500	117,000
55,000	74.9	469	1870	4220	7500	14,500	20,700	26,900	42,500	58,000	89,200	120,000
60,000	74.9	469	1870	4220	7500	16,200	23,300	30,400	48,300	66,100	102,000	137,000
65,000	74.9	469	1870	4220	7500	16,900	24,800	32,500	51,800	71,200	110,000	148,000
70,000	74.9	469	1870	4220	7500	16,900	26,200	34,600	55,400	76,300	118,000	160,000
75,000	74.9	469	1870	4220	7500	16,900	27,700	36,800	59,300	81,900	127,000	17[illegible],000
80,000	74.9	469	1870	4220	7500	16,900	29,000	38,700	62,900	87,100	135,000	184,000
85,000	74.9	469	1870	4220	7500	16,900	30,000	40,800	66,900	93,000	145,000	197,000
90,000	74.9	469	1870	4220	7500	16,900	30,000	43,400	71,700	100,000	157,000	213,000
95,000	74.9	469	1870	4220	7500	16,900	30,000	45,500	75,300	106,000	167,000	228,000
100,000	74.9	469	1870	4220	7500	16,900	30,000	47,700	80,400	113,000	179,000	244,000

[redacted]

TABLE E.3 - Average Falling Rates of Various Sized Particles for 5000 ft Increment

Altitude (1000)ft	Average Rates of Fall (ft/hr)											
	10 µ	25 µ	50 µ	75 µ	100 µ	150 µ	200 µ	250 µ	375 µ	500 µ	750 µ	1000 µ
0 - 5	54.5	341	1360	3070	4780	7,840	10,900	13,900	21,600	29,200	44,400	59,700
5 - 10	57.4	359	1430	3230	5100	8,370	11,700	14,900	23,100	31,200	47,600	64,000
10 - 15	58.4	366	1460	3290	5330	8,790	12,300	15,700	24,400	33,000	50,300	67,600
15 - 20	59.7	373	1490	3360	5610	9,310	13,000	16,700	25,900	35,200	53,500	72,000
20 - 25	60.9	381	1530	3430	5880	9,790	13,700	17,600	27,400	37,200	56,700	76,300
25 - 30	62.6	392	1570	3530	6190	10,400	14,500	13,700	29,100	39,400	60,300	81,000
30 - 35	65.6	411	1640	3700	6640	11,200	15,600	20,200	31,300	42,500	65,000	87,400
35 - 40	68.3	427	1710	3840	6920	12,000	16,800	21,800	33,900	46,200	70,600	94,900
40 - 45	70.4	440	1760	3970	7040	12,800	18,100	23,400	36,700	50,000	76,400	102,900
45 - 50	73.2	458	1820	4120	7320	13,800	19,600	25,300	39,700	54,200	83,000	112,000
50 - 55	74.9	469	1870	4220	7500	14,400	20,500	26,600	41,900	57,200	87,900	118,500
55 - 60	74.9	469	1870	4220	7500	15,400	22,000	28,700	45,400	62,200	95,600	129,000
60 - 65	74.9	469	1870	4220	7500	16,600	24,100	31,500	50,100	68,600	106,000	143,000
65 - 70	74.9	469	1870	4220	7500	16,900	25,500	33,600	53,600	73,800	114,000	154,000
70 - 75	74.9	469	1870	4220	7500	16,900	27,000	35,700	57,400	79,100	122,500	166,000
75 - 80	74.9	469	1870	4220	7500	16,900	28,400	37,800	61,100	84,500	131,000	178,000
80 - 85	74.9	469	1870	4220	7500	16,900	29,500	39,800	64,900	90,100	140,000	191,000
85 - 90	74.9	469	1870	4220	7500	16,900	30,000	42,100	69,300	96,500	151,000	205,000
90 - 95	74.9	469	1870	4220	7500	16,900	30,000	44,500	73,900	103,000	162,000	221,000
95 - 100	74.9	469	1870	4220	7500	16,900	30,000	46,600	78,100	109,500	173,000	236,000

[redacted]

APPENDIX F

DETERMINATION OF MATERIAL BALANCE FOR SHOT 1 FALLOUT PATTERN (r/hr at 1 hr)

In determining the material balance for a given fallout pattern, it is necessary to relate the amount of activity accounted for within the fallout contours to that produced in the detonation.

The gamma field surveys of the outer islands were made from 8 to 10 days after Shot 1. The following material balance was calculated for time t = 0 + 9 days. Selection of this time eliminated the introduction of any possible errors due to extrapolation of the field measurements to early times. Furthermore, experimental data on the gamma energy spectrum were available for this time period.

F.1 PER CENT OF DEVICE ACTIVITY AT TIME (t)

Let Y_t = total No. of photons/sec at time (t)

F = fission yield of the device in KT

A = No. of fissions/KT of yield

N_t = d/s/10^4 fissions at time (t)

r_t = beta particle to gamma photon ratio at time (t)

then

$$Y_t = \frac{F\ A\ N_t \times 10^{-4}}{r_t} \quad \text{photons/sec}$$

$F = 9000 \pm 1000$ KT

$A = 1.5 \times 10^{23}$

$N_t = 4.93 \times 10^{-3}$

$r_t = 0.45$

[redacted]

Computation of N_t was made for Shot 5 at 0 + 9 days.[4] Consideration was made of the contribution from fission products as well as that from U^{239} and U^{237} induced activities. Since the capture to fission ratio for Shot 1 and Shot 5 were nearly the same these data were assumed reasonably valid for Shot 1 calculations. Similarly the beta particle to gamma photon ratio calculated for Shot 5 at 0 + 9 days was used in this evaluation.[4]

Therefore,

$$Y_t = \frac{(9 \times 10^3)(1.5 \times 10^{23})(4.93 \times 10^{-3})(10^{-4})}{0.45}$$

$$Y_t = 1.47 \times 10^{21} \text{ photons/sec at } 0 + 9 \text{ days.}$$

F.2 RELATION OF DEPOSITED ACTIVITY TO GAMMA FIELD AT 3 FT FOR AN INFINITE CONTAMINATED PLANE

Let I_t = radiation intensity in r/hr at time (t) 3 ft above an infinite contaminated smooth plane

K = a constant which includes the air absorption coefficient

A_t = deposited activity in μc/sq cm at time (t)

E_t = average gamma source energy in Mev/disintegration at time (t)

then[17],

$$I_t = KA_tE_t.$$

Let B = dose build up factor[6] or the ratio of the dose from all photons to that from unscattered photons

R = source energy degradation caused by roughness of the plane[10]

then,

$$I_t' = (KA_tE_t)(B)(R).$$

where

I_t' = radiation intensity at time (t) in r/hr at 3 ft as measured in the field

[redacted] A

or

$$A_t = \frac{I_t'}{K\ E_t\ B\ R}\ \mu c/\text{sq cm};$$

however,

$$\text{photons/sec/sq cm} = \frac{(\mu c/\text{sq cm})(3.7 \times 10^4)}{r_t}$$

and

$$E_t = \frac{E_t'}{r_t}$$

where

E_t' = average gamma energy in Mev/photon.

Therefore,

$$A_t = \frac{(I_t')(3.7 \times 10^4)}{(K)(E_t'/r_t)(B)(R)(r_t)} = \frac{3.7 \times 10^4\ I_t'}{K\ E_t'\ B\ R}\ \text{photons/sec/sq cm.}$$

Let I_t' = 1 r/hr at 0 + 9 days

K = 0.12 (ref 7)

B = 1.45 (ref 6)

R = 0.60 (ref 10)

E_t' = 0.344 Mev/photon at 0 + 8 days.

The value of the average gamma energy was experimentally determined from a Shot 5 sample at 0 + 8 days.4/ The gamma spectrum experienced little change over the period 0 + 8 to 0 + 10 days and its applicability to Shot 1 calculations has been indicated.*

Therefore,

$$A_t = \frac{(3.7 \times 10^4)(1)}{(0.12)(0.344)(1.45)(0.60)}$$

$$A_t = 1.03 \times 10^6 \text{ photons/sec/sq cm at } 0 + 9 \text{ days}$$

---

* Private communication from C.S.Cook, USNRDL

[redacted]

or

> 1 r/hr at 0 + 9 days is produced by an infinitely contaminated plane of uniformly deposited activity of 1.03 x 10^{6} photons per sec per sq cm.

F.3 CALCULATION OF MATERIAL BALANCE

The fallout pattern was evaluated out to the 100 r/hr at 1 hr contour by measuring the areas between contours in sq cm and assuming the arithmetical average of the peripheral contours as the average level of activity for the area segment between the contours. There is some indication that the average value of activity between contours is not arithmetical. However, existing field data do not indicate any one continuous function that describes it precisely. Material balance data for Shot 1 are given in Table F.1.

TABLE F.1 - Material Balance, Shot 1

Contours considered in determination of areas (Fig. 6.6) (r/hr at 1 hr)	Average levels between contours at 0 + 9 days (r/hr)	Area (sq cm)	Total rate (photons/sec)
3000 to center of pattern	3.42	5.3×10^{13}	1.87×10^{20}
2000 to 3000	2.85	7.5×10^{13}	2.2×10^{20}
1000 to 2000	1.71	1.0×10^{14}	1.76×10^{20}
500 to 1000	0.86	1.56×10^{14}	1.38×10^{20}
100 to 500	0.342	3.35×10^{14}	1.18×10^{20}

Therefore, within the 100 r/hr at 1 hr contour 8.39×10^{20} photons per sec are accounted for at 0 + 9 days.

$$\frac{8.39 \times 10^{20}}{1.47 \times 10^{21}} = 0.57$$

Thus, 57 per cent of the device activity is accounted for.

F.4 FRACTION OF THE DEVICE COLLECTED IN TOTAL COLLECTOR, STATION 251.03

A radiochemical analysis 18/ on the fallout collected at Station 251.03, where the gamma field reading was 1 r/hr at 0 + 9 days, yielded a value of the bomb fraction over a 1 sq ft area to be 1.5×10^{-13}. This

[redacted]

value was obtained from a total collector sample and must be corrected for collector efficiency which at this dose rate was 43 per cent (see Fig. 4.1). Therefore, the experimentally determined bomb fraction per square foot for a gamma field of 1 r/hr at 9 days equals

$$\frac{1.5 \times 10^{-13}}{0.435} = 3.45 \times 10^{-13}/\text{sq ft} = 3.7 \times 10^{-16}/\text{sq cm}.$$

Since 1 r/hr at 9 days is produced by 1.03×10^{6} photons/sec/sq cm and $Y_t = 1.47 \times 10^{21}$ photons/sec/sq cm the calculated fraction of the device at this station is

$$\frac{1.03 \times 10^{6}}{1.47 \times 10^{21}} = 7.0 \times 10^{-16}/\text{sq cm}.$$

[redacted]

APPENDIX G

STATION INSTRUMENTATION

TABLE G.1 - Shot 1 - Lagoon Station Instrumentation

Station Code	Total Collector	Differential Fallout Collector	Gummed Paper	Film Badge	Triple Collector[a]	Remarks
250.01						Not set out
250.02	X[b]	X	X	X	X	Chemical Corps raft present
250.03	X	X	X	X	X	
250.04	X	X	X	X	X	Chemical Corps raft present
250.05	X	X	X	X	X	Chemical Corps raft present
250.06	X	X	X	X	X	
250.07	X	X	X	X	X	
250.08	X	X	X	X	X	Chemical Corps raft present
250.09						LASL and Chemical Corps rafts present
250.10	X	X	X	X	X	LASL raft present
250.11	X	X	X	X	X	
250.12	X	X	X	X	X	Chemical Corps and two LASL rafts present
250.13	X	X	X	X	X	Chemical Corps and two LASL rafts present
250.14	X	X	X	X	X	
250.15	X	X	X	X	X	
250.16						NRDL raft missing
250.17	X	X	X	X	X	
250.18	X	X	X	X	X	
250.19						NRDL raft missing
250.20						NRDL raft missing
250.21						NRDL raft missing
250.22	X	X	X	X	X	
250.23						NRDL raft missing
250.24	X	X	X	X	X	
250.25	X	X	X	X	X	
250.26	X	X	X	X	X	Located on reef between William and Yoke

(a) For Project 2.6a.
(b) X indicates instrument placed.

[redacted]

TABLE G.2 - Shot 1 - Island Station Instrumentation

Station Code	Total Collector	Differential Fallout Collector	Gummed Paper	Film Badge	Triple Collector[a]	Automatic Water Drop Collector[a]	Electrostatic Precipitator[a]	Gamma Time-Intensity Recorder	Rain Gage	Remarks
251.01										Not set up
251.02	X[b]	X	X	X	X	X			X	
251.03	X	X	X	X	X	X		X	X	
251.04	X	X	X	X	X	X			X	
251.05	X	X	X	X	X	X			X	
251.06	X	X	X	X	X	X			X	
251.07	X	X	X	X	X	X			X	
251.08	X	X	X	X	X	X	X		X	
251.09	X	X	X	X	X	X	X	X	X	
251.10	X	X	X	X	X	X	X		X	

(a) For Project 2.6a

(b) X indicates instrument placed

[redacted]

TABLE 4.3 - Shot 1 - Lagoon Station Recovery

Station Code	Total Collector	Differential Fallout Collector	Gummed Paper	Film Badge	Triple[a] Collector	Remarks
250.02						Raft demolished
250.03						Raft missing
250.04	X[b]	X	X	(X)N1	(X)Lid did not close	
250.05	X	X	X	(X)N[illegible]	(X)Lid did not close	
250.06	X	X	X	(X)N16	(X)Lid did not close	
250.07						Raft missing
250.08						Raft missing
250.09						Chemical Corps and LASL rafts present
250.10						NRDL raft upside down LASL deck smashed
250.11						Raft upside down
250.12						LASL raft decks broken NRDL raft upside down Chem.Corps raft present
250.13						LASL raft deck smashed NRDL raft upside down Chem.Corps raft present
250.14						Raft upside down
250.15						Raft upside down
250.17	Missing	X	X	(X)N34	X	
250.18						Station not prepared
250.22	X	X	X	(X)N3	(X)Lid did not close	
250.24	X	X	X	(X)N35	(X)Lid did not close	
250.25	X	Did not work	X	(X)N10	X	
250.26						Raft upside down

(a) For Project 2.6a.
(b) X indicates instrument recovered.

[redacted]

TABLE G.4 - Shot 1 - Island Station Recovery

Station Code	Total Collector	Differential Fallout Collector	Gummed Paper	Film Badge	Triple[a] Collector	Automatic Water Drop Collector[a]	Gamma Time-Intensity Recorder	Rain Gage	Remarks
251.02	X[b]	X	X	(X)N5	X	Did not function			
251.03	X	Did not work	X	(X)N6	X	Did not function	X		
251.04	X	X	X	(X)N12	X	Did not function			
251.05	X	X	X	(X)N11	X	Did not function			
251.06	X	X	X	(X)N13	X	Did not function		X	
251.07	X	X	X	(X)N25 (X)N31	X	Did not function		X	
251.08	X	Did not trigger	X	(X)N26 (X)N29	Did not trigger	Did not trigger		Sand present	Trigger did not work
251.09	Missing	Full of sand. Did not trigger	X	(x)N27 (X)N28	X Bottles full of water. Did not open	Full of sand	Damaged	Damaged. Full of sand and water	Wave over island damaged equipment
251.10	X	X	X	(X)N30 (X)N32	X	Damaged		Full of sand	Station damaged

(a) For Project 2.6a

(b) X indicates instrument recovered

[redacted]

TABLE G.5 - Shot 2 - Lagoon Station Instrumentation

Station Code	Total Collector	Gummed Paper	Film Pack	Remarks
250.02	X(a)	X		Buoy
250.04				Buoy missing 25 March
250.05	X	X	X	Buoy and raft
250.06	X	X	X	Buoy and raft
250.07	X	X		Buoy
250.08	X	X		Buoy
250.09				Buoy and raft missing 24 March
250.10	X	X	X	Buoy and 2 rafts on reef 24 March
250.11			X	Buoy and raft, M boat ran down buoy
250.12	X	X	X	Buoy and raft
250.13	X	X	X	Buoy and raft
250.14	X	X	X	Buoy and raft
250.15	X	X	X	Buoy and raft
250.16	X	X	X	Buoy near Coca 24 March
250.17	X	X	X	Raft
250.18	X	X	X	Buoy and raft
250.19	X	X	X	Buoy
250.22	X	X	X	Buoy and raft
250.24	X	X	X	Buoy and raft
250.25	X	X	X	Buoy and raft

(a) X indicates instrument placed

[redacted]

TABLE G.6 - Shot 2 - Island Station Instrumentation

Station Code	Total Collectors	Gummed Paper	Differential Fallout Collector	Electrostatic Precipitator	Film Pack	Triple[a] Collectors	Remarks
251.02	X[b]	X			X	X	
251.03	X	X	X		X	X	
251.04	X	X	X		X	X	
251.05	X	X			X	X	
251.06	X	X	X		X	X	
251.07	X	X			X		
251.08	X	X	X	X	X		
251.09	X	X			X		
251.10	X	X	X	X	X		

(a) For Project 2.6a

(b) X indicates instrument placed

[redacted]

TABLE G.7 - Shot 2 - Lagoon Station Recovery

Station Code	Total Collectors	Gummed Paper	Film Pack	Remarks
250.02				Buoy missing
250.05				Raft OK
250.06				Stations OK
250.07				Replaced mast on buoy
250.08				Buoy missing
250.10				Buoy OK, raft turned over
250.11				Buoy OK, raft turned over
250.12				Buoy OK, raft turned over
250.13				Buoy OK, 1 raft upside down, other OK
250.14				Stations OK
250.15				Buoy OK, raft upside down
250.16				Buoy OK
250.17				Raft OK
250.18				Stations OK
250.19				Buoy OK
250.22				Raft OK
250.24				Station missing
250.25				Station missing

All the equipment in the lagoon was left in place since no fallout was received.
All buoy masts were broken.

[redacted]

TABLE G.8 - Shot 2 - Island Station Recovery

Station Code	Total Collectors	Gummed Paper	Differential Fallout Collector	Film Pack	Triple[(a)] Collectors
251.02			Demolished		(X)[(b)] Opened Did not close
251.03				(X)N62	
251.04			Did not operate		Did not open
251.05			Did not operate		
251.06				(X)P2	
251.07				X	
251.08				X	
251.09					
251.10				(X)N63	

All the samples were left in place as no fallout collected except for film badges as noted.

(a) For Project 2.6a.
(b) X indicates instrument recovered.

TABLE G.9 - Shot 3 - Lagoon Station Instrumentation

Station Code	Total Collector	Gummed Paper	Film Pack	Remarks
250.05	X[(a)]	X	X	Raft and buoy
250.06	X	X	X	Buoy and raft
250.07	X	X		Buoy
250.08	X	X		Buoy
250.09	X			Chem.Corps raft
250.10	X	X	X	Buoy and raft
250.11	X	X	X	Buoy and raft
250.12	X	X	X	Buoy and raft
250.13	X	X	X	Buoy and raft
250.14	X	X	X	Buoy and raft
250.15	X	X	X	Buoy and raft
250.16	X	X	X	Buoy
250.17	X	X	X	Raft
250.18	X	X	X	Buoy and raft
250.19	X	X	X	Buoy
250.22	X	X	X	Buoy and raft
Coca	X	X		

(a) X indicates instrument placed.

[redacted]

TABLE G.10 - Shot 3 - Island Station Instrumentation

Station Code	Total Collector	Gummed Paper	Film Pack	Differential Fallout Collector	Triple Collectors[a]	Remarks
251.02	X[b]	X	X			
251.03	X	X		X	X	
251.04	X	X	X	X	X	
251.05	X	X	X			
251.06	X	X	X	X	X	
251.07	X	X	X	X		
251.08	X	X	X	X		
251.09	X	X	X			
251.10	X	X	X	X		Electrostatic Precipitator placed

(a) For Project 2.6a.
(b) X indicates instrument placed.

TABLE G.11 - Shot 3 - Lagoon Station Recovery

Station Code	Total Collector	Gummed Paper	Film Pack	Remarks
250.05	X[a]	X		Raft and buoy
250.06	X	X	(X)P-8	Raft
250.07	X	X		Buoy
250.08	X			Buoy
250.09	X			Chemical Corps raft
250.10				Missing
250.11				Raft turned over, buoy broken
250.12	X		(X)P-12	Buoy mast broken
250.13	X		X	Raft
250.14	X		X	Raft
250.15	X	X		Raft upside down, buoy OK
250.16	X	X		Buoy
250.17	X	X	X	Raft
250.18	X	X		Raft and buoy
250.19	X	X		Buoy only
250.22	X	Destroyed		
Coca	X			

(a) X indicates instrument recovered.

[redacted]

TABLE G.12 - Shot 3 - Island Station Recovery

Station Code	Total Collector	Gummed Paper	Film Pack	Triple Collectors[a]	Differential Fallout Collector	Remarks
251.02	X[b]	X				
251.03	X	X	Missing	(X) Opened Did not close		
251.04	X	Torn	(X)N67	X		
251.05			(X)N70			
251.06			(X)NL8	(X) Opened Did not close	OK No samples	Did not recover
251.07			(X)NL20			
251.08	X		(X)NL6		OK No sample	
251.09			(X)NL5			Station ruined
251.10	X	X	(X)NL15	X	(X)OK	Recovered Electro-static Precipitator

(a) For Project 2.6a.
(b) X indicates instrument recovered.

[redacted]

TABLE G.13 - Shot 4 - Lagoon Station Instrumentation

Station Code	Total Collectors	Gummed Paper	Film Pack	Remarks
250.05	X[a]	X	X	
250.06	X	X		
250.07	X	X		
250.08	X	X		
250.12	X	X		
250.13	X	X		
250.14	X	X		
250.15	X	X		
250.16	X	X		
250.17	X	X	X	
250.18	X	X	X	
250.19	X	X		
250.22	X	X	X	
Coca	X	X	X	

(a) X indicates instrument placed.

TABLE G.14 - Shot 4 - Island Station Instrumentation

Station Code	Total Collectors	Gummed Paper	Film Pack	Triple[a] Collectors	Differential Fallout Collectors	Remarks
251.02	X[b]	X	X		Removed	
251.03	X	X	X	X	X	
251.04	X	X	X	(X) Wired open	X	
251.05	X	X	X	(X) Wired open	(X) Not operating	
251.06	X	X	X	(X) Wired open	X	
251.07						Not set up
251.08	X	X	X		(X) Not operating	
251.09	X	X	X	Removed	Removed	
251.10	X	X	X	X	X	

(a) For Project 2.6a.
(b) X indicates instrument placed.

[redacted]

TABLE G.15 - Shot 4 - Lagoon Station Recovery

Station Code	Total Collectors	Gummed Paper	Film Pack	Remarks
250.05	X[a]	X	(X) NL-10 U8, U33	Buoy and raft
250.06				Station missing
250.07	X	X		
250.08				Station destroyed
250.12				Station missing
250.13				Station missing
250.14				Station missing
250.15				Station missing
250.16				Station missing
250.17	Missing	Destroyed	(X) U38-U39	
250.18	X	Missing	(X) U28-U37	
250.19	X	X		
250.22	X	X	(X) U35-U16	
Coca	X	X	(X) U4, U29	

(a) X indicates instrument recovered.

[redacted]

TABLE G.16 - Shot 4 - Island Station Recovery

Station Code	Total Collectors	Gummed Paper	Film Pack	Triple(a) Collectors	Remarks
251.02					Not recovered
251.03	X(b)	X	(X) NL-2	(X) opened but did not close	
251.04	X		(X) NL-12	X	Equipment destroyed Wave over island
251.05	X	X	(X) NL-4	X	TC and triple collector combined
251.06	X	Destroyed	(X) NL-17	(X) combined with total collector	Equipment ruined by wave
251.08	Did not recover	X	(X) NL-1		
251.09			(X) NL-9		Equipment ruined by wave
251.10			(X) NL-19		Equipment ruined by wave

(a) For Project [illegible].5a.
(b) X indicates instrument recovered.

[redacted]

TABLE G.17 - ECHO Land and Lagoon Station Instrumentation
(Shot Cancelled)

Station Code	Differential Fallout Collector	Triple[a] Collector	Low Film Pack	High Film Pack	Total Collector	Gummed Paper
LAND						
Irene		X[b]				
Bruce	X					
Yvonne	X					
Wilma	X					
LAGOON						
250.27			(X)S34	(X)S8	X	X
250.28			(X)S36		X	X
250.30			(X)S24		X	X
250.31		X	(X)S33		X	X
250.32			(X)S32	(X)S6	X	X
250.33			(X)S31	(X)S7	X	X
250.34			(X) ?			
250.35	X		(X)S37		X	X
250.36		X	(X)S35		X	X
250.37						
250.38			(X)S16			
250.39	X		(X)S40	(X)S9	X	X
250.41			(X)S17		X	X
250.42	X	X	(X)S28		X	X
250.43			(X)S26	(X)S2	X	X
250.44			(X)S23	(X)S3	X	X
250.45			(X)S15		X	X
250.46			(X)S4		X	X
250.47			(X)S22		X	X
250.48		X	(X)S29	(X)S1	X	X
250.49	X	X	(X)S39		X	X
250.50			(X)S41	(X)S10	X	X
250.51						
250.54			(X)S13	(X)S4	X	X
250.55	X		(X)S21		X	X
250.57			(X)S14		X	X
250.58			(X)S12		X	X
Tok			(X)S30		X	X
Mack			(X)S27		X	X
Oscar			(X)S25		X	X

(a) For Project 2.6a.
(b) X indicates instrument placed.

[redacted]

TABLE G.18 - Shot 6 - Land and Lagoon Station Instrumentation

Station Code	Differential Fallout Collector	Triple(a) Collector	Low Film Pack	High Film Pack	Automatic(a) Water Drop Collector	Total Collector	Gummed Paper
LAND							
Leroy	X(b)	X	(X)S48:Stn43,Stn37	(X)U51:Stn28,Stn27	X		
Alice	X	X	(X)S50:Stn44,Stn45	(X)S55:Stn34,Stn35	X	X	X
Janet	X	X	(X)S54 or S43: Stn40, Stn41	(X)S54 or S43: Stn32, Stn33	X	X	X
Nancy	X		(X)S47:Stn38,Stn39	(X)Stn30,Stn31	X	X	X
LAGOON							
250.27			(X)S34	(X)S8		X	X
250.28			(X)S36	(X)U47		X	X
250.30			(X)S24	(X)U50		X	X
250.31			(X)S33	(X)U53		X	X
250.32			(X)S32	(X)S6		X	X
250.33	X		(X)S31	(X)S7, U49		X	X
250.34			(X)S18	(X)S56		X	X
250.35			(X)S37			X	X
250.36			(X)S35	(X)U42		X	X
250.37	X		(X)S20	(X)S5, U52		X	X
250.38	X		(X)S16	(X)U48		X	X
250.39			(X)S40	(X)S9		X	X
250.41			(X)S17 or S19	(X)S58		X	X
250.42	X	X	(X)S28	(X)U40		X	X
250.43			(X)S26	(X)S2		X	X
250.44			(X)S2[illegible]	(X)S3		X	X
250.45			(X)S15	(X)U46		X	X
250.46			(X)S42			X	X
250.47			(X)S22			X	X
250.48			(X)S29	(X)S1		X	X

(a) For Project 2.6a. (b) X indicates instrument placed.

[redacted]

TABLE G.18 - Shot 6 - Land and Lagoon Station Instrumentation (Continued)

Station Code	Differential Fallout Collector	Triple(a) Collector	Low Film Pack	High Film Pack	Automatic(a) Water Drop Collector	Total Collector	Gummed Paper
LAGOON							
250.49	X(b)	X	(X)S39	(X)U43		X	X
250.50			(X)S41	(X)S10, U44		X	X
250.51			(X)S38	(X)U41		X	X
250.54	X		(X)S13	(X)S4		X	X
250.55	X		(X)S21	(X)U45		X	X
250.57			(X)S14, S49	(X)S57		X	X
250.58			(X)S12			X	X
Mack			(X)S27			X	X
Oscar			(X)S25			X	X
Tok			(X)S30			X	X

(a) For Project 2.6a.
(b) X indicates instrument placed.

In addition, there were "reproducibility arrays" on Leroy and Alice. Both were circular arrangements (100 ft dia.) of steel posts holding total collectors (TC) and gummed papers. The Alice station was composed of 5 TC (and gummed papers) on the periphery of the circle, and 1 TC in center; the Leroy array was made up of 6 TC (and gummed papers) on the periphery and 1 TC in center.

[redacted]

TABLE G.19 - Shot 6 - Lagoon Station Recovery

Station Code	Total Collector	Gummed Paper	Film Pack	Differential Fallout Collector	Triple Collector[a]	Remarks
250.27	X[b]	X	X			Evidence of burning
250.28	X	X	X			
250.30	X	Missing	X			
250.31						Superstructure on raft missing
250.32	X	Missing	X			Evidence of burning
250.33	X	X	X	X		
250.34	X	X	X			
250.35	X	X	X			
250.36	X	Missing	X			
250.37	X	X	X	Did not operate		Raft drifted to position on reef 2 mi NW of Leroy
250.38						Raft missing
250.39	X	X	X			
250.41	X	X	X			
250.42						Raft on reef - inaccessible
250.43						Raft missing
250.44	X	X	X			
250.45						Raft missing
250.46						Raft missing
250.47	X	X	X			
250.48	X	X	X			
250.49	X	X	X	X	X	Triple collector opened, did not shut
250.50	X	X	X			
250.51	X	X	X			
250.54	X	X	X	X		
250.55	X	X	X	X		
250.57						Not recovered
250.58	X	X	X			
Mack	X	Missing	X			
Oscar	X	X	X			
Tok						Not recovered

(a) For Project 2.6a.
(b) X indicates instrument recovered.

[redacted]

TABLE C.20 - Shot 6 - Land Station Recovery

Station Code	Total Collector	Gummed Paper	Film Pack	Differential Fallout Collector	Triple[a] Collector	Automatic[a] Water Drop Collector	Remarks
Leroy	X[b]	X	X	Did not operate	Did not operate	Did not operate	Blast trigger did not work
Alice	X	Missing	X	Jammed	Destroyed	Did not operate	
Janet	X	Missing	X	X	(X) Opened, did not close	Did not operate	
Nancy	X	X	X	Jammed		Did not operate	

(a) For Project 2.6a.
(b) X indicates instrument recovered.

[redacted]

APPENDIX H

MARSHALL ISLAND OCEAN CURRENTS AS DETERMINED FROM FREE FLOATING BUOYS

TABLE H.1 - Ocean Current Data Obtained at IVY

Code	Launched		Recovered		Set (Degrees True)	Drift (Knots)
	Time	Position	Time	Position		
Oct-Nov 1952						
J	312245	10°37'N 164°45'E	021810	10°43.5'N 164°13'E	281	0.70
K	312048	11°01'N 164°54'E	030650	11°23.5'N 164°25'E	307	0.60
L	311858	11°26'N 165°00'E	031410	11°44'N 164°36.3'E	305	0.43
M	311652	11°52.5'N 164°58.9'E	031930	12°10.3'N 164°20'E	293	0.61
N	311451	12°19.2'N 164°58.9'E	032200	12°39.5'N 164°04'E	202	0.73
O	311248	12°42.0'N 164°50'E	040000	13°06'N 163°58'E	295	0.70
Q	310800	13°25'N 164°22'E	041355	13°38.8'N 163°02.8'E	290	0.77
R	310557	13°08'N 164°06'E	041740	13°13.3'N 162°39'E	274	0.78
S	310340	12°50'N 163°49'E	042040	12°46'N 162°10'E	268	0.85
A	292030	12°29'N 164°21'E	042150	12°41'N 162°18.8'E	275	0.89
B	290830	12°05'N 164°42'E	050520	12°09'N 162°28'E	272	0.87
E	291230	10°50'N 164°33'E	060115	10°45.5'N 162°23.0'E	267	0.69

The above buoys were standard Navy balsa wood DAN buoys equipped with sea anchor, 12-ft mast, and wire mesh corner radar reflector stop mast.

[redacted]

TABLE H.2 - Ocean Current Data Obtained at CASTLE

Code	Launched		Recovered		Set (degrees true)	Drift (knots)
	Time	Position	Time	Position		
February 1954						
A3	141021	12°00'N 165°23'E	161725	11°55'N 164°49'E	261	0.60
B2	131543	11°43'N 162°23'E	141450	11°45.5'N 162°09.6'E	278	0.57
B3	131635	11°51.3'N 162°25.2'E	141532	11°49.1'N 162°10.2'E	261	0.64
February-March 1954						
DWL	281740	11°59.5'N 164°44'E	021258	11°55.5'N 164°26.5'E	258	0.40
DWI	281705	11°56.5'N 164°49'E	021104	11°52'N 164°33.5'E	253	0.37
DWC	281454	11°43.5'N 164°55.7'E	021104	11°41.5'N 164°40.5'E	255	0.35
DWO	281630	11°55.2'N 164°34.2'E	021625	11°50.5'N 164°16.3'E	255	0.37
March 1954						
G5	270018	11°25'N 166°08'E	271615	11°19'N 166°03.'E	216	0.43
F5	262250	11°42'N 166°11'E	271738	11°34'N 166°07'E	207	0.48
E5	262146	11°57.5'N 166°11'E	271900	11°50'N 166°05'E	215	0.43
D5	262027	12°14'N 166°01.7'E	272100	12°03'N 165°54'E	232	0.39
A5	261613	12°35.3'N 165°21.2'E	281518	12°20.5'N 164°26'E	255	1.18

[redacted]

TABLE H.2 - Ocean Current Data Obtained at CASTLE (Cont.)

Code	Launched Time	Launched Position	Recovered Time	Recovered Position	Set (degrees true)	Drift (knots)
A4	261432	12°19'N 165°21.7'E	281313	12°32'N 164°48'E	291	0.77
T4	261520	12°16.3'N 165°09'E	281210	12°28'N 164°41.5'E	293	0.65
R4	261705	12°04.5'N 164°52'E	280845	12°01'N 164°41.3'E	251	0.27
Q4	261758	11°56.5'N 164°48.3'E	281823	11°52'N 164°36.6'E	248	0.25
P4	261850	11°44'N 164°43.5'E	272045	11°39'N 164°41.6'E	204	0.21
O4	261946	11°29.3'N 164°46.5'E	271930	11°26.6'N 164°43'E	238	0.19
April 1954						
A1	021242	11°28.6'N 162°44'E	031450	11°34.5'N 162°26.6'E	290	0.67
B1	021415	11°50.5'N 162°37.5'E	031325	11°48'N 162°26'E	258	0.50
D1	021732	11°34'N 162°01'E	031035	11°40'N 161°53.5'E	336	0.37
D2	150700	12°18'N 166°19.5'E	170745	12°31'N 165°46'E	291	0.71
E2	150500	12°01'N 166°28'E	171300	11°59'N 166°00'E	265	0.50
F1	151313	11°37'N 166°05'E	171600	11°24'N 165°30'E	249	0.82
F2	150300	11°42'N 166°31'E	171600	11°29'N 165°56'E	249	0.82

The above buoys were constructed of a metal can 30 in. in diameter with approximately 12-in. freeboard. They were equipped with a sea anchor and a 10-ft mast, and had approximately 1 sq ft wind resistance atop the mast.

[redacted]

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